JOURNAL OF AGRICULTURAL RESEARCH

VOLUME 57

JULY 1–DECEMBER 15, 1938

ISSUED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE
WITH THE COOPERATION OF THE ASSOCIATION OF
LAND-GRANT COLLEGES AND UNIVERSITIES

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1939

Gift of U.S. Gov't

JOINT COMMITTEE ON POLICY AND MANUSCRIPTS

FOR THE UNITED STATES DEPARTMENT OF AGRICULTURE

H. G. KNIGHT, CHAIRMAN
Chief, Bureau of Chemistry and Soils

JOHN W. ROBERTS
Principal Pathologist, Bureau of Plant Industry

BENJAMIN SCHWARTZ
Principal Zoologist, Chief, Zoological Division, Bureau of Animal Industry

FOR THE ASSOCIATION OF LAND-GRANT COLLEGES AND UNIVERSITIES

S. W. FLETCHER
Director of Research, Pennsylvania Agricultural Experiment Station

L. E. CALL
Director, Kansas Agricultural Experiment Station

C. E. LADD
Director, New York (Cornell) Agricultural Experiment Station

EDITORIAL SUPERVISION

M. C. MERRILL
Chief of Publications, United States Department of Agriculture

Articles for publication in the Journal must bear the formal approval of the chief of the department bureau, or of the director of the experiment station from which the paper emanates. Each manuscript must be accompanied by a statement that it has been read and approved by one or more persons (named) familiar with the subject. The data as represented by tables, graphs, summaries, and conclusions must be approved from the statistical viewpoint by someone (named) competent to judge. All computations should be verified.

Station manuscripts and correspondence concerning them should be addressed to S. W. Fletcher, Director of Research, Pennsylvania Agricultural Experiment Station, State College, Pa.

Published on the 1st and 15th of each month. This volume will consist of 12 numbers and the contents and index.

Subscription price:

Entire Journal: Domestic, $3.25 a year (2 volumes).
Foreign, $4.75 a year (2 volumes).

Single numbers: Domestic, 15 cents.
Foreign, 20 cents.

Articles appearing in the Journal are printed separately and can be obtained by purchase at 5 cents a copy domestic; 8 cents foreign. If separates are desired in quantity, they should be ordered at the time the manuscript is sent to the printer. Address all correspondence regarding subscriptions and purchase of numbers and separates to the Superintendent of Documents, Government Printing Office, Washington, D. C.

630.61
U58j
v.57

JUL 28 1939
437347
B.P.

JOURNAL OF AGRICULTURAL RESEARCH

VOL. 57 WASHINGTON, D. C. JULY 1–DECEMBER 15, 1938

CONTENTS

Page

Effect of Different Soil Colloids and Whole Soils on the Toxicity of Sodium Selenate to Millet. PHILIP L. GILE, HUBERT W. LAKIN, and HORACE G. BYERS. Illus. 1

Growth Substance and the Development of Crown Gall. S. B. LOCKE, A. J. RIKER, and B. M. DUGGAR. Illus. 21

A Photoelectric Sorter for Length Measurements of Fibers of Seed Cotton. BURT JOHNSON. Illus. 41

Variability in Germination of Freshly Harvested *Avena*. F. A. COFFMAN and T. R. STANTON. 57

Two Distinct Strains of the Nematode *Aphelenchoides fragariae* Occuring on Strawberry Plants in the United States. J. R. CHRISTIE. Illus. 73

Preservation of Cyanogenetic Plants for Chemical Analysis. REINHOLD R. BRIESE and JAMES F. COUCH. 81

Relation of Atmospheric Conditions to Enlargement Rate and Periodicity of Winesap Apples. C. P. HARLEY and M. P. MASURE. Illus. 109

The Solubility of Casein in Salts of Certain Organic Acids, and Its Fractionation by Means of These Acids. RALPH H. MCKEE and STEPHEN P. GOULD. 125

Relation of Bitterness to the Toxic Principle in Sweetclover. WILLIAM K. SMITH and R. A. BRINK. 145

Cytology of Twin Cotton Plants. J. M. WEBBER. Illus. 155

Moisture Movement in Wood Above the Fiber-Saturation Point. LOUIS W. REES and STANLEY J. BUCKMAN. Illus. 161

The Effect of Natural Selection in a Mixture of Barley Varieties. H. V. HARLAN and M. L. MARTINI. Illus. 189

Effect of Neutral Salts of Sodium and Calcium on Carbon and Nitrogen of Soils. V. P. SOKOLOFF. 201

An Apparent Induced Loss of Nitrogen-Fixing Ability in *Azotobacter*. CHARLES R. STUMBO and P. L. GAINEY. Illus. 217

The Reactions of Wireworms to Arsenicals. CHARLES E. WOODWORTH. 229

Rate of Spread of Surface Fires in the Ponderosa Pine Type of California. JOHN R. CURRY and WALLACE L. FONS. Illus. 239

Anatomy of the Leaf and Stem of *Gossypium*. IRMA E. WEBBER. Illus. 269

Two Mastigosporium Leaf Spots on Gramineae. RODERICK SPRAGUE. Illus. 287

Preliminary Biochemical Studies on Effects of Certain Environmental Factors on Development and Composition of the Peanut. SAMUEL L. JODIDI. 301

Inflorescence Blight of the Date Palm. J. G. BROWN and KARL D. BUTLER. Illus. 313

Experiments on the Transmission of Potato Viruses by Vectors. T. P. DYKSTRA and W. C. WHITAKER. Illus. 319

Vertical Migration, Distribution, and Survival of Infective Horse Strongyle Larvae Developing in Feces Buried in Different Soils. JOHN T. LUCKER. Illus. 335

Effect of Infestation With the Nematode *Cooperia curticei* on the Nutrition of Lambs. JOHN S. ANDREWS. Illus. 349

A Method of Determining Root Knot Resistance in Beans and Cowpeas in the Seedling Stage. KEITH C. BARRONS. Illus. 363

Hood and Supernumerary Spike Development in Barley. O. T. BONNETT. Illus. 371

Influence of Japanese Beetle Instar on the Sex and Population of the Parasite *Tiphia popilliavora*. M. H. BRUNSON. 379

Microchemical Studies of Potato Tubers Affected With Blue Stem Disease. L. M. HILL and C. R. ORTON. Illus. 387

Page

A Comparison of the Vitamin D Potency of the Stemmy and Leafy Portions of Alfalfa Hay. G. C. WALLIS 393
Foliar Diagnosis in Relation to Development and Fertilizer Treatment of the Potato. WALTER THOMAS and WARREN B. MACK. Illus 397
Observations on Muskrat Damage to Corn and Other Crops in Central Iowa. PAUL L. ERRINGTON 415
Toxic and Repellent Properties of Some Inorganic and Organic Compounds and Mixtures in Grasshopper Baits. CHARLES H. RICHARDSON and EDWIN J. SEIFERLE 423
Proteolytic Activity in Relation to the Blackening of Potatoes After Cooking. A. FRANK ROSS and W. E. TOTTINGHAM. Illus 433
Morphology of the Digestive Tract of the Blackfly (*Simulium nigroparvum*). JAMES A. COX. Illus 443
Seasonal Variations in the Carbohydrate and Nitrogen Content of Roots of Bearing Pecan Trees. C. L. SMITH and J. G. WAUGH. Illus 449
Applicability of Nutrient-Solution Purification to the Study of Trace-Element Requirements of Rhizobium and Azotobacter. ROBERT A. STEINBERG 461
Digestible Nutrients and Metabolizable Energy in Certain Silages, Hays, and Mixed Rations. F. W. CHRISTENSEN and T. H. HOPPER 477
The Relation of Color and Carotene Content of Roughage in the Dairy Ration to the Color, Carotene Content, and Vitamin A Activity of Butterfat. R. E. HODGSON, J. C. KNOTT, H. K. MURER, and R. R. GRAVES. Illus 513
The Effect of Environmental Temperature on Mortality, Rate of Growth, and Utilization of Food Energy in White Leghorn Chicks. C. F. WINCHESTER and M. KLEIBER. Illus 529
Some Physiological Studies of Crown Gall and Contiguous Tissue. R. NAGY, A. J. RIKER, and W. H. PETERSON. Illus 545
Studies on Probable Damage by Blister Rust in Some Representative Stands of Young Western White Pine. THOMAS W. CHILDS and J. W. KIMMEY. Illus 557
The Essentiality of Gallium to Growth and Reproduction of *Aspergillus niger*. ROBERT A. STEINBERG 569
Time Interval Between Clutches in Rhode Island Red Pullets. F. A. HAYS. Illus 575
Relation Between Fiber Length and Maturity in Cotton. R. S. HAWKINS. Illus 583
A Mosaic Disease of Turnip. C. M. TOMPKINS. Illus 589
Assays of Riboflavin and the Filtrate Factor in Certain Milk Products. T. H. JUKES and G. A. RICHARDSON 603
Relation of Soil Temperature to Chlorosis of Gardenia. LINUS H. JONES. Illus 611
Resistance in the Red Raspberry to the Mosaic Vector *Amphorophora rubi* Kalt. GLENN A. HUBER and C. D. SCHWARTZE. Illus 623
The Carotene Content of Market Hays and Corn Silage. HERBERT G. WISEMAN, EDWARD A. KANE, LEO A. SHINN, and C. A. CARY. Illus 635
Host-Parasite Relations in Red Clover Plants Resistant and Susceptible to Powdery Mildew, *Erysiphe polygoni*. OLIVER F. SMITH. Illus 671
Differentiation of Wood-Decaying Fungi by Their Reactions on Gallic or Tannic Acid Medium. ROSS W. DAVIDSON, W. A. CAMPBELL, and DOROTHY J. BLAISDELL. Illus 683
An Analysis of the Blood of the Sixth-Instar Southern Armyworm (*Prodenia eridania*). FRANK H. BABERS 697
The Biological Disposition of Rotenone After Ingestion by the Southern Armyworm. P. A. WOKE 707
Sampling Error in Timber Surveys. A. A. HASEL. Illus 713
A Study of Protein Extract From Soybeans With Reference to Its Use in Food. SYBIL WOODRUFF, EVELYN CHAMBERS, and HELEN KLAAS. Illus 737
Linkage of the Q B Gs Group in Sorghum. J. C. STEPHENS and J. R. QUINBY. Illus 747
Further Investigations of Brown-Staining Fungi Associated With Engraver Beetles (*Scolytus*) in White Fir. ERNEST WRIGHT. Illus 759
Complete or Partial Inhibition of Flowering in Certain Plants When Days Are Too Short or Too Long. H. A. ALLARD. Illus 775

Page

Stagonospora Leaf Spot and Root Rot of Forage Legumes. FRED REUEL JONES and J. L. WEIMER. Illus. 791

Histology of Apple Fruit Tissue in Relation to Cracking. LEIF VERNER. Illus. 813

Physiological Conditions Which Produce Wing Development in the Pea Aphid. CARL W. SCHAEFER. Illus. 825

The Growth Curve of Sorghum. A. T. BARTEL and J. H. MARTIN. Illus. 843

Correlations Between Biological Essentiality and Atomic Structure of the Chemical Elements. ROBERT A. STEINBERG. 851

Laboratory Studies on *Tetrastichus xanthomelaenae* Rond. and *Tetrastichus* sp., Two Hymenopterous Egg Parasites of the Elm Leaf Beetle. P. A. BERRY. Illus. 859

Effect of Exterior Temperature Upon Press Fluid, Shear Force, and Cooking Losses of Roasted Beef and Pork Muscles. ALICE M. CHILD and MARY J. SATORIUS. Illus. 865

Respiration and Lactic Acid Production by a Fungus of the Genus *Rhizopus*. SELMAN A. WAKSMAN and J. W. FOSTER. Illus. 873

Determination and Occurrence of Boron in Natural Phosphates, Superphosphate, and Defluorinated Phosphate Rocks. LEWIS F. RADER, JR., and W. L. HILL. Illus. 901

The Anatomical Development of *Lepidium draba*. AUSTIN O. SIMONDS. Illus. 917

Black Ring, a Virus Disease of Cabbage and Other Crucifers. C. M. TOMPKINS, M. W. GARDNER, and H. REX THOMAS. Illus. 929

Soil-Fertility Standards for Growing Northern Conifers in Forest Nurseries. S. A. WILDE. 945

ERRATA AND AUTHORS' EMENDATION

Page 5, table 1, column 4, "P_2O_1" should be "P_2O_5."

Page 6, table 2, column 3, "$Al_2\ O_3\ K\ Fe_2\ O_3$" should be "$Al_2\ O_3 + Fe_2\ O_3$."

Page 116, second line from bottom, after the word "growth" the remainder of the paragraph should read: "as does evaporating power. Mean atmospheric temperatures, on the other hand, seem to be somewhat negatively correlated with growth in the last two periods, but not in the first."

Page 118, line 11, delete the word "evaporation."

Page 149, tenth line from bottom of text, "microscopically" should be "macroscopically."

Page 164, tenth line from bottom, insert "g" after "0.01."

Page 168, table 2, line 2, column 11, change "0.00341" to "0.00314."

Page 173, sixth line from bottom, "sapwood" should be "heartwood," and seventh line from bottom, "in" should be "from" and "heartwood" should be "sapwood."

Page 347, line 15, the first "152 days" should be "126 days."

Page 356, table 5, column 8, heading "Nitrogen free" should be "Nitrogen free extract."

Page 357, table 7, column 7, "−26.74" should be "+26.74."

Page 398, table 1, column 2, under "Plot No.," the 18th number, "4," should be "14;" the 20th number "8", should be "10;" and the next to last number, "10," should be "16."

Page 403, "figure 1" should be "figure 2," and page 411, "figure 2" should be "figure 1."

Page 410, table 6, next to last word in heading, "dry-weather" should be "dry-weight."

Page 426, table 1, last column, "100" appearing beneath "percent" should align with "22" appearing below "Hours" and all succeeding figures through "93" should be correspondingly aligned. The first "0" after "93" should be deleted.

Page 455, line 4, delete the word "below."

Page 463, eighth line from bottom, "2 to 4 million bacteria" should read "10 to 20 million bacteria."

Page 468, line 11, "465" should be "467."

Page 482, line 1, "1924" should be "1923."

Page 484, table 2, column 7, next to last line, "35.55" should be "36.55."

Page 489, table 4, column 8, line 5, "1.998" should be "1.988;" column 6, ninth line from bottom, "21.83" should be "2.183;" and column 7, sixteenth line from bottom, "4.22" should be "0.422."

Page 491, table 4, column 7, line 3, "2.36" should be "0.236."

Page 493, the second line in paragraph 2 should be inserted between the first and second line in paragraph 1.

Page 496, table 5, next to the last column, line 7, "7.864" should be "78.64."

Page 503, table 7, last column, line 8, "29.6" should be "29.7."

Page 504, table 8, last column, line 4, "41.8" should be "14.8;" "Trial 8" should be "Trial 13," and "Trial 17" should be "Trial 16;" and column 3, line 3, "48.5" should be "43.9."

Page 507, table 10, last column, line 6, "+0308" should be "−.0308."

Page 509, table 11, "Trial 19" should be "Trial 21."

Page 531, line 5, insert "See" before "Almquist."

Page 543, line 15, $\frac{\text{"food−excreta+100"}}{\text{food}}$ should be $\frac{\text{"food−excreta 100"}}{\text{food}}$

Page 570, table 1, tenth line from bottom of table, column 2, "44.36" should be "443.6."

Page 603, line 2, "chicks [3]" should be "chicks (3) [3]."

Page 606, last line, "Diet 96 (7)" should be "Diet 96 (4)."

Page 625, the positions of the illustrations in figures 1 and 2 should be reversed.

Page 640, line 5, "0.195" should be "0.1915."

Page 642, line 5 of text, "0.5" should be "0.05."

Page 686, second line from bottom, columns 4 and 6, only one minus sign should be used.

Page 687, line 9, columns 4 and 6, only one minus sign should be used.

Page 733, table 10, first column, third line from bottom, "20 by 70" should be "20 by 80."

Page 738, plate 1, the material in "*A*" should be "*B*," and that in "*B*" should be "*A*."

Page 753, table 3, column 2, next to last line of factors, "gags" should be "Gsgs."

Page 818, line 5, "plate 2, A" should be "plate 5, B."

Page 868, table 1, column 1, second line from bottom, insert "t" at the beginning of the line.

Page 876, table 2, column 1, lines 1 and 2, insert "3" and "4," respectively, in place of leaders.

Page 917, under heading, Materials and Methods, line 16, insert "95 percent" between "48 cc of" and "alcohol."

Page 946, table 3, column 5, insert "Pounds" above figures.

JOURNAL OF AGRICULTURAL RESEARCH

VOL. 57 WASHINGTON, D. C., JULY 1, 1938 NO. 1

EFFECT OF DIFFERENT SOIL COLLOIDS AND WHOLE SOILS ON THE TOXICITY OF SODIUM SELENATE TO MILLET[1]

By PHILIP L. GILE, *senior chemist*, HUBERT W. LAKIN, *assistant chemist*, and HORACE G. BYERS, *principal chemist, Soil Chemistry and Physics Research Division, Bureau of Chemistry and Soils, United States Department of Agriculture*

INTRODUCTION

Investigations of the occurrence of selenium in soils, shales, waters, and vegetation in the United States have been reported by Byers (*2, 3*).[2] In the course of these investigations it became important to know whether the toxicity of selenium compounds to plants varies with the character of the soil. Previous studies by Hurd-Karrer (*8, 9*) indicate that this is the case, since she found that the amount of selenium absorbed by the plant and its injurious effect are markedly influenced by the sulphate available in the soil. She also found that the toxicity of sodium selenate varied with other characteristics of the soil, since sodium selenate was more injurious to wheat in Pierre clay than in Keyport clay loam (*9*). No systematic study, however, has been made of the toxicity of selenium compounds in different types of soil.

The results reported in this paper deal with the effects of different soil colloids and of different whole soils on the toxicity of sodium selenate to millet. The effects of the colloids on the absorption of selenium from the selenate applications are also considered. It should be emphasized that this study concerns only selenium applied as sodium selenate, since work in progress shows that quite different results are obtained when selenium is applied as sodium selenite.

METHODS

The method of investigation first adopted was the same as that followed in a previous study, which dealt with the effects of soil colloids on the toxicity of calcium arsenate (*6*). Foxtail millet (*Setaria italica* (L.) Beauv.) was grown in quartz sand with which sufficient soil was mixed to give a soil-colloid content of approximately 1 percent. Different quantities of sodium selenate were applied. The quantity of selenium required to reduce the yield one-half was determined for each mixture from a graph of yields plotted against selenate applications. This half-toxicity value for the sand-soil mixture was compared with the half-toxicity value of a parallel, pure quartz-sand series, and the difference between the two values was taken as the effect of the soil colloid on the toxicity of sodium selenate. The advantages of this method and the objections to it have been discussed in previous publications (*5, p. 4; 6, p. 478*).

[1] Received for publication August 24, 1937; issued July 1, 1938.
[2] Italic numbers in parentheses refer to Literature Cited, p. 19.

Each pot, filled with pure quartz sand or with a sand-soil mixture, received 0.93 g of potassium nitrate, 0.33 g of ammonium sulphate, 0.0185 g of ferric tartrate, 0.42 g of magnesium chloride ($MgCl_2.6H_2O$), and 0.0015 g of manganese sulphate ($MnSO_4.2H_2O$). From 0.27 to 0.94 g of monocalcium phosphate per pot was supplied, the quantity being varied according to the capacity of the soil for rendering phosphate unavailable to millet.

Essentially the same method was used in the experiments with whole soils.

Glazed earthenware pots holding about 5,000 g of quartz sand were used as containers. They were kept in a greenhouse, and the moisture content was maintained at 15 percent with distilled water. Ten millet plants per pot were grown for periods ranging from 18 to 35 days, according to the season. The plants were forming joints when cut. Only the parts of the plant above ground were harvested. Most of these were later analyzed for selenium by the method described by Williams and Lakin (*17*). Two experiments were also conducted with Marquis wheat (*Triticum aestivum* L.) grown for 48 days, and one experiment was conducted with White London mustard (*Brassica alba* (L.) Boiss.) grown for 26 days.

All except two of the soils used in these experiments were parts of samples utilized in former studies of soil colloids. Data regarding them are given in the following Department of Agriculture publications: Nos. 190, 195, 298, and 300 in Department Bulletins 1193 and 1311 (*7*, *14*); Nos. 6678, 6679, 6718, 6719, 6842, 6977, 8736, and 8737 in Technical Bulletin 316 (*11*); Nos. B–407 and 9475 in Technical Bulletin 430 (*12*); No. 9804 in Technical Bulletin 484 (*4*); and No. B–1086 in Technical Bulletin 502 (*1*). The Keyport clay loam was a sample of surface soil from the Arlington Experiment Farm of the Department of Agriculture at Arlington, Va., and the Clarion loam was a surface soil from Ames, Iowa. These two soils have not been analyzed. Selenium in some form has been found in most of the soils (*15*), but none of them contain selenium sufficiently available to millet to impart more than 1 part per million to the dry substance of the plant.

EXPERIMENTS CONDUCTED WITH QUARTZ SAND AND SAND-SOIL MIXTURES

Some preliminary tests were made to determine the amount of selenium that would reduce the yield of millet to about one-half that of the checks. The experiments reported in table 1 were then conducted. The medium for growth was in all cases either pure quartz sand or a sand-soil mixture containing approximately 1 percent of soil colloid. Table 1 contains data for calculating the quantities of selenium required to reduce the yield of millet one-half in seven different sand-soil mixtures. It also contains data showing the manner in which increasing quantities of selenate decrease the yield, and the effects of phosphate and sulphate on the toxicity of the selenate.

The manner in which the yield decreases with increasing quantities of sodium selenate is shown in figure 1. The curves in this figure represent averages of results obtained in quartz sand and in different sand-soil mixtures in experiments 1, 2, 4, 5, and 6, table 1. Percentage yields rather than actual yields are given in this graph, the

weight of plants grown without selenium being taken as 100. The use of relative values facilitates averaging the widely different actual yields obtained in the different experiments. It is apparent from the form of the curve that the quantities of selenium required to reduce the yield to between 60 and 15 percent of normal can be determined with considerable accuracy.

Incidentally, it may be noted that this curve for the toxicity of sodium selenate has the same form as the curve obtained for the toxicity of calcium arsenate (*6*). Both toxicity curves are similar to Mitscherlich's (*13*) curve for increased growth with increase in the minimum factor in that the toxicity curves are Mitscherlich's curve turned upside down.

These results are sufficient to show that soluble sulphates should be kept approximately constant in comparing the effects of different

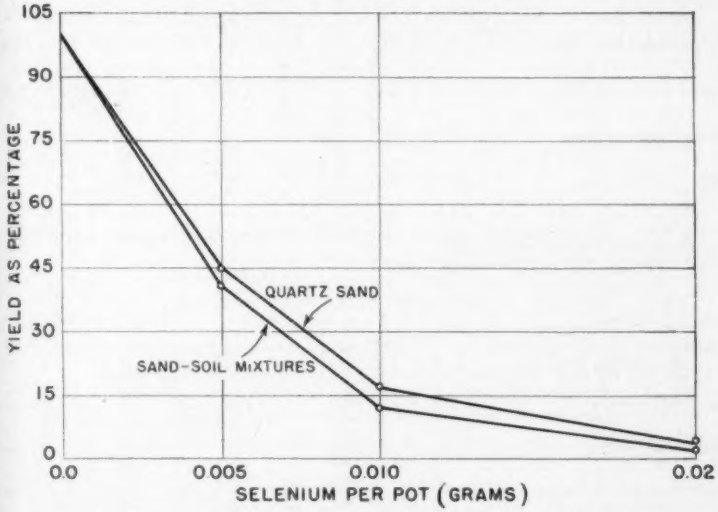

FIGURE 1.—Effect of increasing quantities of sodium selenate on yield of millet. Yield with no silicate = 100.

soils on selenate toxicity. In the experiments on the effects of the soil colloids the available sulphate applied was 0.24 g of SO_4 per pot unless otherwise noted. This quantity was largely in excess of the crop's requirements, since in experiment 6, wherein the influence of sulphate application was tested, the plants receiving no selenium gave approximately the same yield with 0.024 g of SO_4 as with the usual 0.24 g. This quantity is also large as compared with the quantities of soluble SO_4 naturally present in the soils added to the quartz sand in different experiments. Small variations obtaining in different experiments at this comparatively high level of available SO_4 would not be expected to affect appreciably the half-toxicity values, since a threefold increase in SO_4 in experiment 1 (the excess sulphate occurring in the superphosphate application) increased the half-toxicity figure by only about 60 percent and a 90-percent decrease in SO_4 in experiment 6 only halved the toxicity figure.

TABLE 1.—*Effect of different soil colloids on the toxicity of sodium selenate to plant growth*

[All soils added to quartz sand in sufficient quantity to supply 1 percent of colloid; millet grown except as otherwise indicated]

EXPERIMENT 1 (OCT. 15 TO NOV. 17)

Laboratory no.	Kind of soil mixed with quartz sand	Depth	P_2O_5 applied per pot	Sodium selenate added per pot, expressed, as Se	Air-dry yield of plants per pot				Selenium in air-dry plants	Half-toxicity value (Se required per pot to reduce yield one-half)
					Series A	Series B	Series C	Average		
		Inches	*Gram*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*P. p. m.*	*Gram*
	Quartz sand only		0.20	0.000	3.00	2.40	3.87	3.09	0	0.0047
				.005	1.41	1.21	1.83	1.48	400	
				.010	.44	.83	.56	.61	690	
				.020	.07	.14	.12	.11	1,500	
190	Wabash silt loam	15–36	.20	.000	5.12	4.92	5.18	5.08	0	[1] .0057
				.010	.51	.45	.37	.44	1,300	
				.020	.06	.09	.08	.08	1,900	
9804	Columbiana clay	0–10	.50	.000	5.19	4.13	4.99	4.77	0	[1] .0053
				.010	.44	.48	.43	.45	1,100	
				.020	.02	.05	.06	.04		
9804	do	0–10	[2] .50	.000	4.02	4.72	4.42	4.39	0	[2] .0080
				.010	1.43	1.36	2.18	1.66	400	
				.020	.41	.36	.39	.39	1,000	

[1] This value is a little higher than the true value because of the curvature of the toxicity curve (see fig. 1) and interpolation between distant points.
[2] Superphosphate instead of monocalcium phosphate.

EXPERIMENT 2 (FEB. 11 TO MAR. 18)

	Quartz sand only		0.15	0.000	3.69	2.88	2.79	3.12		0.0054
				.005	1.87	1.50	1.71	1.69		
				.010	.48	.56	.48	.51		
298	Manor loam	7–20	.40	.000	5.14	5.53	5.15	5.27		.0044
				.005	2.13	2.16	2.43	2.24		
				.010	.35	.68	.63	.55		
195	Clarksville silt loam	0–10	.25	.000	5.14	3.99	4.66	4.60		.0047
				.005	2.04	2.32	2.15	2.17		
				.010	.60	.80	.78	.73		
8737	Marshall silt loam	13–24	.25	.000	5.15	4.60	4.92	4.89		.0048
				.005	1.88	2.65	2.28	2.27		
				.010	.77	.59	.66	.67		

EXPERIMENT 3 (JAN. 14 TO FEB. 25)

	Quartz sand only		0.10	0.000	2.48	2.91		2.70		0.0060
				.007	1.21	1.03		1.12		
	do		.20	.000	3.32	3.87		3.60		.0043
				.007	.67	.61		.64		
	do		.30	.000	3.76	3.54		3.65		.0044
				.007	.73	.76		.75		

EXPERIMENT 4 (APR. 1 TO MAY 1)

	Quartz sand only		0.225	0.000	3.47	1.65	3.59	2.90		0.0038
				.005	1.00	.48	1.50	.99	400	
				.010	.37	.50	.49	.45		
	do		.45	.000	3.45	2.90	3.14	3.16		.0046
				.005	.64	.94	1.12	.90		
				.010	.26	.28	.38	.31		

TABLE 1.—*Effect of different soil colloids on the toxicity of sodium selenate to plant growth*—Continued

EXPERIMENT 5 (JUNE 20 TO JULY 8)

Laboratory no.	Kind of soil mixed with quartz sand	Depth	P_2O_5 applied per pot	Sodium selenate added per pot, expressed as Se	Air-dry yield of plants per pot				Selenium in air-dry plants	Half-toxicity value (Se required per pot to reduce yield one-half)
					Series A	Series B	Series C	Average		
		Inches	*Gram*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*P. p. m.*	*Grm*
	Quartz sand only		0.15	0.000	2.10	2.54	2.19	2.28		0.0043
				.005	.92	1.04	.89	.95	590	
				.010	.34	.37	.33	.35		
8736	Marshall silt loam	0–13	.15	.000	5.42	5.33	5.42	5.39		.0038
				.005	1.81	1.67	2.11	1.86		
6977	Cecil sandy clay loam	0–6	.40	.000	4.40	3.38	4.14	3.97		.0037
				.005	1.21	1.46	1.39	1.35		
EXPERIMENT 6 (OCT. 11 TO NOV. 15), THE USUAL 0.24 G SO_4 PER POT ADDED										
	Quartz sand only		0.20	0.000	1.76	1.45	1.63	1.61		0.0046
				.005	.54	.84	.80	.73	550	
8736	Marshall silt loam	0–13	.20	.000	2.10	2.08	2.30	2.16		.0043
				.005	.76	.97	.98	.90	790	
6977	Cecil sandy clay loam	0–6	.53	.000	1.98	2.22	2.33	2.18		.0041
				.005	.92	.74	.82	.83	740	
EXPERIMENT 6 (OCT. 11 TO NOV. 15), ONLY 0.024 G SO_4 PER POT ADDED										
	Quartz sand only		0.20	0.000	1.40	1.32	1.27	1.33		0.0025
				.005	.01	.01	.04	.02		
8736	Marshall silt loam	0–13	.20	.000	2.29	2.23	2.30	2.27		.0025
				.005	.01	.01	.01	.01		
6977	Cecil sandy clay loam	0–6	.53	.000	1.94	2.22	2.12	2.12		.0025
				.005	.01	.03	.01	.02		
EXPERIMENT 7 (NOV. 27 TO JAN. 14), WHEAT GROWN INSTEAD OF MILLET										
	Quartz sand only		0.15	0.000	2.92	3.32	3.24	3.16	(1)	0.0072
				.010	.82	.96	1.08	.95	1,700	
				.020	.27	.28	.20	.25	2,500	
6977	Cecil sandy clay loam	0–6	.40	.000	3.07	3.30	3.80	3.39	(1)	.0070
				.010	.99	1.00	.88	.96	1,700	
				.020	.15	.22	.25	.21	3,200	
EXPERIMENT 8 (APR. 3 TO APR. 29), MUSTARD GROWN INSTEAD OF MILLET										
	Quartz sand only		0.20	0.000	1.98	1.31	1.94	1.74		0.0051
				.005	.87	.95	.86	.89		
				.010	.64	.49	.43	.52		
				.020	.22	.08	.20	.17		

The effects of soil colloids on the toxicity of sodium selenate are shown in table 2, which summarizes experimental results given in table 1. All data in the table pertain to millet except those in the last line, which apply to wheat. It will be seen that additions of widely different soils to quartz sand, up to 1 percent of colloidal matter, in no case diminish the toxicity of sodium selenate. In fact, the quantity of selenate producing one-half injury is slightly less in the sand-soil mixtures than in pure quartz sand in every case except the two noted as not accurately determined. Evidently, then, within the limits of error inherent in the method, soil colloids have no effect

on the availability of sodium selenate. This conclusion is based on the results of only seven soils, but the colloids of these soils have silica-sesquioxide ratios ranging from 3.33 to 0.81. Moreover, the effects produced by these same soils on superphosphate (*5*) and on calcium arsenate in previous work (*6*) covered pretty well the range of effects produced by a much greater number of soils.

TABLE 2.—*Toxicity to millet of sodium selenate in sand-soil mixtures containing 1 percent of soil colloid*

Experiment No.	Kind of soil mixed with quartz sand	Molecular ratio of SiO_2 to Al_2O_3 Fe_2O_3 of colloidal material	Half-toxicity value (Se required per pot to yield one-half)		Se in plants (calculated for application of 0.005 g Se per pot) [1]	
			In sand-soil mixture	In quartz sand	In sand-soil mixture	In quartz sand
			Gram	*Gram*	*P. p. m.*	*P. p. m.*
1	Wabash, No. 190	3.33	[1] 0.0057	0.0047	650	400
5	Marshall, No. 8736	2.91	.0038	.0043		
6	do	2.91	.0043	.0046	790	550
2	Marshall, No. 8737	2.88	.0048	.0054		
2	Clarksville, No. 195	2.18	.0047	.0054		
2	Manor, No. 298	1.81	.0044	.0054		
5	Cecil, No. 6977	1.34	.0037	.0043		
6	do	1.34	.0041	.0046	740	550
1	Columbiana, No. 9804	.81	[1] .0053	.0047	550	400
7	Cecil, No. 6977 [2]	1.34	.0070	.0072	850	850

[1] Values a little too high (see footnote 1, experiment 1, table 1).
[2] Wheat was grown instead of millet.

It was necessary to ascertain whether the toxicity of sodium selenate is affected by variations in the available phosphate, since the phosphate supply presumably varied somewhat in the different sand-soil series. As mentioned previously, phosphate applications were varied according to the capacities of the different soils for phosphate fixation, and these capacities were merely estimated. The effect of different quantities of monocalcium phosphate on selenate toxicity in quartz sand is shown in experiments 3 and 4 in table 1. In experiment 3 the quantities of selenium required to reduce the yield one-half were 0.006, 0.0043, and 0.0044 g with 0.10, 0.20, and 0.30 g of P_2O_5, respectively; in experiment 4 the half-toxicity values were 0.0038 and 0.0046 g of selenium with 0.225 and 0.45 g of P_2O_5, respectively. These differences are hardly significant. Apparently, then, moderate quantities of available phosphate in excess of the plant's requirements have little or no influence on the toxicity of sodium selenate.

That sulphate ions diminish the toxicity of sodium selenate has been demonstrated by Hurd-Karrer (*8*). The degree of this influence, in terms of the half-toxicity value, is shown in part of experiment 1 and in experiment 6, table 1. In experiment 1 superphosphate was compared with monocalcium phosphate in the Columbiana sand-soil mixture. In the monocalcium phosphate series of this experiment the quantity of sulphate (SO_4) per pot was 0.24 g, whereas in the superphosphate series there must have been roughly 1 g of soluble SO_4 per pot. This increase in sulphate is doubtless responsible for raising the half-toxicity value from 0.0053 to 0.0080 g of selenium per pot. In experiment 6 the effects of 0.024 and 0.24 g of SO_4 per pot

were compared in quartz sand and in Marshall and Cecil soil-sand mixtures. With 0.024 g of SO_4 the half-toxicity values were 0.0025 g of selenium for all three mediums, whereas with 0.24 g of SO_4 the half-toxicity values were 0.0046, 0.0043, and 0.0041 g of selenium.

The toxicity values given in table 2 apparently are fairly accurate. The agreement of determinations duplicated in experiments 5 and 6 indicates that one-half a milligram in the toxicity values is sufficient allowance for errors and variations in the actual conduct of the experiments. Possible errors inherent in the method of experimentation may be somewhat larger than those involved in carrying out the experiments. The addition of soil undoubtedly renders the sand a better medium for growth, as shown by the comparative yields in sand and in sand-soil mixtures without selenium (table 1). That this improvement in conditions for growth does not increase, but rather decreases, the selenate needed to produce one-half injury is possibly due to the fact that it increases the absorptive capacity of the plant. At all events, plants in the sand-soil mixtures contain a higher concentration of selenium in the parts above ground than plants in pure sand, as shown in the last two columns of table 2. The results of the wheat experiment (last line of table 2, and experiment 7, table 1) confirm this idea. In this experiment the yield without selenate is about the same in pure sand as in the soil-sand mixture, and the concentration of selenium in the plant is practically the same for the two mediums.

The preceding experiments give no indication that soil colloids form a selenate compound unavailable to plants. But it is possible that soil colloids do have an effect on selenate which is too slight to be measured in experiments with only 1 percent of colloidal material. It is also possible that larger quantities of soil colloids might affect the plant's absorption of selenate in some way other than through the formation of an insoluble compound. Experiments were therefore conducted to measure the toxicity of sodium selenate in different whole soils.

EXPERIMENTS CONDUCTED WITH WHOLE SOILS

The experiments with whole soils were similar to those with the sand-soil mixtures just described. Each experiment included a series with pure quartz sand to serve as a standard for comparing the results of experiments conducted at different times. Eight soils received precipitated calcium carbonate as follows: The Columbiana and Nacogdoches soils, 1 g per pot; the Marshall, Cecil, Chester, and Muskingum soils, 2 g per pot; and the Manor and Keyport soils, 3 g per pot. The fertilizer applied to the soil consisted of 1.40 g of KNO_3, 0.33 g of $(NH_4)_2SO_4$, 0.136 g of NH_4Cl, and different quantities of monocalcium phosphate, depending on the estimated needs of the soil. This fertilizer is somewhat different from that applied to the sand-soil mixtures, but the quantity of sulphate applied is the same. Sodium selenate was added in solution along with the potassium and ammonium salts. The fertilizer applied to the quartz sand series was the same as in the work with sand-soil mixtures. Water added, and kept constant by weighing, was sufficient to give a uniform water content from top to bottom of the pot. The quantity was about 60 percent of the water-holding capacity of the soil and ranged in different soils from 715 to 1,250 cc per pot.

Most of the experiments were conducted to determine the quantities of selenate required to reduce the yield one-half in different soils. But experiments were also conducted to find to what extent the half-toxicity values were affected by the concentration of sulphate, by the quantity of phosphate, and by the manner in which the selenate was applied. The detailed results of the different experiments are given in table 3.

TABLE 3.—*Effect of different whole soils on the toxicity of sodium selenate to plant growth*

[Millet grown except as otherwise indicated]

EXPERIMENT 9 (JUNE 20 TO JULY 8)

Laboratory	Kind of soil	Depth	P_2O_5 applied per pot	Sodium selenate added per pot, expressed as Se	Air-dry yield of plants per pot				Selenium in air-dry plants	Half toxicity value Se required per pot to reduce yield one-half
					Series A	Series B	Series C	Average		
		Inches	*Grams*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*P. p. m.*	*Gram*
	Quartz sand		0.15	0.000	2.10	2.54	2.19	2.28	0	.0043
				.005	.92	1.04	.89	.95	500	
				.010	.34	.37	.33	.35		
6977	Cecil sandy clay loam	0–6	4.00	.000	4.88	4.94	4.54	4.79		.0069
				.005	3.05	3.29	2.91	3.08		
				.010	1.36	1.33	1.29	1.33		
8736	Marshall silt loam	0–13	.40	.000	6.94	6.42	5.76	6.37		.0050
				.005	3.26	3.24	3.00	3.17		
				.010	1.02	.90	1.08	1.00		

EXPERIMENT 10 (OCT. 11 TO NOV. 15), 0.24 G. SO_4 ADDED PER POT

	Quartz sand		0.20	0.000	1.76	1.45	1.63	1.61	0	0.0046
				.005	.54	.84	.80	.73	550	
6977	Cecil sandy clay loam	0–6	4.00	.000	2.53	2.44		2.49	0	.0054
				.005	1.10	1.57		1.34	570	
8736	Marshall silt loam	0–13	.53	.000	3.38	3.00		3.19	0	.0071
				.005	2.16	2.02		2.09	560	

EXPERIMENT 10 (OCT. 11 to NOV. 15) NO SULPHATE ADDED TO SOILS; 0.024 G SO_4 PER POT ADDED TO SAND

	Quartz sand		0.20	0.000	1.40	1.32	1.27	1.33		0.0025
				.005	.01	.01	.04	.02		
6977	Cecil sandy clay loam	0–6	4.00	.000	2.72	2.24		2.48		.0028
				.005	.30	.22		.26		
8736	Marshall silt loam	0–13	.53	.000	3.34	3.68		3.51		.0025
				.005	.03	.02		.03		

EXPERIMENT 11 (APR. 1 TO MAY 1) SELENATE ADDED AT TOP OF POT; LOW PHOSPHATE

	Quartz sand		0.225	0.000	3.47	1.65	3.59	2.90		0.0038
				.005	1.00	.48	1.50	.99	400	
				.010	.37	.50	.49	.45		
6977	Cecil sandy clay loam	0–6	2.00	.000	5.28	5.78	5.64	5.57		.0064
				.005	3.70	3.08	3.55	3.44	240	
				.010	1.09	1.07		1.08		
8736	Marshall silt loam	0–13	.20	.000	7.65	8.08	6.68	7.47		.0041
				.005	2.92	2.90	2.78	2.87	400	
				.010	.87	.97		.92	760	

TABLE 3.—*Effect of different whole soils on the toxicity of sodium selenate to plant growth*—Continued

EXPERIMENT 11 (APR. 1 TO MAY 1) SELENATE MIXED WITH SOIL; LOW PHOSPHATE

Laboratory	Kind of soil	Depth	P_2O_5 applied per pot	Sodium selenate added per pot, expressed as Se	Air-dry yield of plants per pot				Selenium in air-dry plants	Half toxicity value Se required per pot to reduce yield one-half
					Series A	Series B	Series C	Average		
		Inches	*Grams*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*P. p. m.*	*Gram*
6977	Cecil sandy clay loam	0–6	2.00	0.000	5.38	6.76	------	6.07	------	0.0079
				.005	4.28	5.06	4.16	4.50	240	
				.010	1.66	2.28	------	1.97	530	
8736	Marshall silt loam	0–13	.20	.000	5.42	4.42	4.90	4.91	------	.0072
				.005	3.52	3.33	3.00	3.28	220	
				.010	1.36	1.83	------	1.60	440	

EXPERIMENT 11 (APR. 1 TO MAY 1) SELENATE ADDED AT TOP OF POT; HIGH PHOSPHATE

6977	Cecil sandy clay loam	0–6	4.00	0.000	5.20	6.85	5.90	5.98	------	0.0066
				.005	3.40	3.78	4.22	3.80	180	
				.010	1.20	1.22	------	1.21	450	
8736	Marshall silt loam	0–13	.40	.000	7.53	6.17	8.01	7.24	------	.0048
				.005	3.43	3.77	3.21	3.48	380	
				.010	1.20	1.16	------	1.18	590	

EXPERIMENT 12 (AUG. 29 TO SEPT. 26)

	Quartz sand	------	0.15	0.000	2.58	2.51	2.88	2.66	0	0.0037
				.005	.83	.90	.94	.89	460	
				.010	.31	.38	.48	.39	1,100	
	Keyport clay loam	------	2.70	.000	6.43	6.14	5.79	6.12	0	.0073
				.005	------	3.59	4.13	3.86	220	
				.010	2.46	1.90	2.05	2.14	530	

EXPERIMENT 13 (FEB. 27 TO APR. 3)

	Quartz sand	------	0.20	0.000	2.22	2.24	1.82	2.09	0	0.0041
				.005	.96	.76	.76	.83	640	
				.010	.32	.28	.39	.33	1,500	
B1086	Spearfish silt loam	0–12	.40	.000	5.77	6.44	4.62	5.61	0	.0072
				.005	3.26	3.88	3.72	3.62	260	
				.010	1.81	1.76	1.70	1.76	630	
	Clarion loam	------	.40	.000	6.10	5.58	4.45	5.38	0	.0061
				.005	2.79	3.48	2.98	3.08	260	
				.010	.88	1.80	1.11	1.26	340	
298	Manor loam	7–20	2.00	.000	4.88	4.80	5.40	5.03	0	.0074
				.005	3.44	3.48	3.28	3.40	250	
				.010	1.81	1.46	1.41	1.56	430	
9804	Columbiana clay	0–10	3.00	.000	3.03	2.90	3.02	2.98	0	
				.005	3.04	2.82	2.91	2.92	110	
				.010	2.82	2.28	2.52	2.54	130	

EXPERIMENT 14 (MAY 24 TO JUNE 18)

	Quartz sand	------	0.20	0.000	4.36	3.94	3.78	4.03	0	0.0042
				.005	1.95	1.38	1.53	1.62	620	
				.010	.62	.60	.64	.62	970	
300	Chester loam	0–8	2.00	.000	4.46	4.83	4.11	4.47	0	.0071
				.005	2.82	2.88	2.74	2.81	610	
				.010	1.41	1.42	1.71	1.51	------	
6718 6719	Vernon fine sandy loam	0–10	.40	.000	4.77	4.76	4.60	4.71	0	.0069
				.005	3.13	2.95	2.60	2.89	340	
				.010	1.35	1.12	1.09	1.19	840	
6842	Colby silty clay loam	2–10	.20	.000	5.97	7.57	7.88	7.14	1	.0060
				.005	3.92	4.10	4.08	4.03	350	
				.010	1.56	1.58	2.00	1.71	570	
9804	Columbiana clay	0–10	5.62	.000	4.88	4.88	------	4.88	0	.0164
				.020	2.02	1.88	------	1.95	540	
				.030	.16	.42	------	.29	780	

TABLE 3.—*Effect of different whole soils on the toxicity of sodium selenate to plant growth*—Continued

EXPERIMENT 15 (SEPT. 1 TO SEPT. 24)

Laboratory	Kind of soil	Depth	P_2O_5 applied per pot	Sodium selenate added per pot, expressed as Se	Air-dry yield of plants per pot				Selenium in air-dry plants	Half toxicity value Se required per pot to reduce yield one-half
					Series A	Series B	Series C	Average		
		Inches	*Grams*	*Gram*	*Grams*	*Grams*	*Grams*	*Grams*	*P. p. m.*	*Gram*
	Quartz sand		0.20	0.000	3.10	3.29	3.09	3.16		0.0037
				.005	1.10	.96	1.01	1.02	750	
				.010	.33	.30	.40	.34	1,100	
B407	Muskingum silt loam	0–7	.27	.000	5.70	5.71	6.09	5.83	0	.0074
				.005	3.86	3.42	4.29	3.86	230	
				.010	2.14	1.73	1.76	1.88	660	
6679	Kirvin fine sandy loam	12–24	2.70	.000	3.18	3.60	3.44	3.41	1	.0101
				.0075	2.02	2.30	2.13	2.15	540	
				.015	.79	.97	.88	.88	1,100	
6678	..... do	0–12	.70	.000	3.70	3.78	3.44	3.64	1	.0057
				.005	1.98	2.28	1.75	2.00	180	
				.010	.59	.52	.41	.51	850	

EXPERIMENT 16 (OCT. 12 TO NOV. 13)

	Quartz sand		0.20	0.000	2.00	2.31	2.63	2.31		0.0053
				.005	1.16	1.22	1.26	1.21	630	
				.010	.43	.36	.32	.37	810	
9475	Nacogdoches fine sandy loam	0–8	2.70	.000	4.15	2.96	2.44	3.18	0	.0050
				.0075	.78	.85	.74	.79	510	
				.015	.10	.25	.30	.22	910	
300	Chester loam	0–8	2.00	.000	4.36	4.66	4.07	4.36		0.0080
				.005	3.19	2.72	3.17	3.03	230	
				.010	1.50	1.75	1.66	1.64	200	

EXPERIMENT 17 (NOV. 27 TO JAN. 14) WHEAT GROWN INSTEAD OF MILLET

	Quartz sand		0.15	0.000	2.92	3.32	3.24	3.16	1	0.0072
				.010	.82	.96	1.08	.95	1,700	
				.020	.27	.28	.28	.28	2,500	
6977	Cecil sandy clay loam	0–6	4.00	.010	2.52	2.67	.....	2.60	750	.0152
				.020	.88	.84	.....	.86	1,600	
8736	Marshall silt loam	0–13	.40	.000	3.14	3.02	.....	3.08	0	0.078
				.010	1.08	1.16	.....	1.12	1,200	
				.020	.20	.15	.....	.18	2,000	

The extent to which the sulphate application affects the toxicity of sodium selenate in the Marshall and Cecil soils is shown in table 3, experiment 10, in which the plants were grown with no sulphate added to the soil and with the addition of 0.24 g of SO_4 per pot. The addition of 0.24 g of SO_4 per pot changed the toxicity value in the Marshall soil from 0.0025 to 0.0071 g of selenium, and in the Cecil soil from 0.0028 to 0.0054 g of selenium. These results with whole soils are similar to those obtained with sand-soil mixtures, and indicate that the influence of the sulphate is about the same for the two mediums.

The effect of phosphate on selenate toxicity is shown in experiment 11, table 3. Doubling the quantity of phosphate applied raised toxicity values in the different soils as follows: From 0.0064 to 0.0066 g of selenium per pot in the Cecil soil, and from 0.0041 to 0.0048 in the Marshall soil. The yields of the pots to which no selenium was added show that the double phosphate application supplied at least twice as much phosphate as was needed. It may be concluded, therefore,

that the toxicity values of the whole soils are not appreciably affected by variations in the phosphate fertilization, up to at least double the requirements of the soil and plant.

In the experiments with whole soils as well as in the preceding experiments with sand-soil mixtures, the sodium selenate and the soluble fertilizer salts were added to the dry soil, dissolved in the total amount of water needed to bring the soil to the optimum water content. Certainly in the case of sand cultures this seemed the best method of applying the selenate, since it gave a uniform distribution of selenate throughout the sand at the beginning of the experiment. It was a question, however, what the distribution of selenate would be at the end of the experiment. It was also questionable whether this method of application would give as fair a comparasion of toxicity values in different whole soils as mixing the selenate with the soil after adding most of the water.

The distribution of selenate in soil and in sand at the end of an experiment was studied by sampling the top, middle, and bottom thirds of soil in a pot and analyzing the three layers for selenium. Pots receiving the larger selenate application in experiment 7, table 1, and experiments 11 and 17, table 3, were subjected to this procedure. The results are given in table 4, together with the half-toxicity values of the soils and the selenium content of the plants above the ground at one-half injury.[3]

TABLE 4.—*Distribution of selenate in different parts of a pot at the end of an experiment*

[Pots receiving larger selenate application in experiment 7, table 1, and experiments 11 and 17, table 3]

Experiment No.	Sodium selenate applied per pot, as gram of selenium	Kind of soil	Crop	How selenate was applied	Selenium present in different layers of soil, as parts per million of soil			Half-toxicity value (selenium required to reduce yield one-half)	Selenium in crop at one-half injury
					Top third	Middle third	Bottom third		
	Gram				*P. p. m.*	*P. p. m.*	*P. p. m.*	*Gram*	*P. p. m.*
7	0.02	Quartz sand	Wheat	At top	2.0	3.5	5.0	0.0072	1,225
7	.02	Sand and Cecil soil	do	do	3.0	3.5	3.5	.0070	1,210
17	.02	Whole Cecil soil	do	do	6.0	3.5	1.0	.0152	1,175
17	.02	Whole Marshall soil	do	do	5.0	3.5	2.0	.0078	900
11	.01	Whole Cecil soil	Millet	do	5.0	3.5	.6	.0064	310
11	.01	do	do	Mixed	2.5	3.0	3.5	.0079	410
11	.01	Whole Marshall soil	do	At top	3.5	3.0	3.0	.0041	330
11	.01	do	do	Mixed	1.0	3.5	5.0	.0072	320

Evidently when the sodium selenate is added at the top of the pot it works downward somewhat in the quartz sand, becomes almost uniformly distributed in the sand-soil mixture, and remains more concentrated in the upper layers in whole soils. On the other hand, when the selenate is mixed uniformly with the whole soil, it tends to become more concentrated in the lower layers during the experiment. In the Marshall soil the selenate evidently moves more freely than in the Cecil. Differences in distribution of the selenate were not due to differences in distribution of moisture, since the water content of

[3] Determination of selenium in the soil samples were made by K. T. Williams.

the three layers of soil was found to be the same within a few tenths of a percent.

The results of the millet experiment (table 4) show that the toxicity of the selenate varies appreciably with its distribution in the soil. Apparently the toxicity is less, that is, the toxicity value is greater, when the selenate accumulates in the lower part of the pot. And since this downward movement is freer in some soils than in others, it should make for inaccuracy in comparing the toxicities of selenate in different soils. However, if it is permissible to generalize from the results of the two soils, the Cecil and the Marshall, it seems that the downward movement is less in soils in which the toxicity is less, that is, the toxicity value is greater. Hence, if a correction were made for inequalities of distribution in different soils, it would involve increasing somewhat the larger toxicity values. One method of application does not seem more accurate than the other for comparing the effects of different soils on selenate toxicity. Therefore, the application in solution was continued, this being the less laborious method.

Experiments to determine to what extent the toxicity of sodium selenate varies in different soils are reported in detail in table 3. The toxicity values for the 14 soils tested and for quartz sand in the same experiments are summarized in table 5. By subtracting the toxicity values for sand from the toxicity values for soils, figures were obtained for the effects of the total colloidal fractions on selenate toxicity. These figures, given in next to the last column, are based on the assumption that the noncolloidal soil material would have the same toxicity value as quartz sand. The specific effects of the different soil colloids, based on the same assumption, are given in the last column. These were obtained by dividing the figure representing the effect of the whole colloid fraction by the percentage of colloid in the soil. All values are given as milligrams of selenium per pot of soil or sand.

TABLE 5.—*Toxicity of sodium selenate in different whole soils and calculated effects of the colloids*

Experiment No.	Kind of soil	Quantity of colloid in soil	Molecular ratio of SiO_2 to Al_2O_3+Fe_2O_3 in colloidal material	Half-toxicity value [1] for the soil	Half-toxicity value [1] for quartz sand in same experiment	Difference between half-toxicity [1] values for soils and for sand	Calculated half-toxicity [1] value for 1 percent of soil colloid per pot
		Percent		*Mg*	*Mg*	*Mg*	*Mg*
14	Colby, No. 6842	30.2	3.41	6.0	4.2	1.8	0.06
9	Marshall, No. 8736	32.4	2.91	5.0	4.3	.7	.02
10	....do	32.4	2.91	7.1	4.6	2.5	.08
11	....do	32.4	2.91	4.1	3.8	.3	.01
13	Spearfish, No. B1086	23.7	2.84	7.2	4.1	3.1	.13
13	Clarion			6.1	4.1	2.0	
14	Vernon, Nos. 6718–19	8.5	2.50	6.9	4.2	2.7	.31
15	Muskingum, No. B407	19.9	2.26	7.4	3.7	3.7	.19
15	Kirvin, No. 6678	5.6	2.02	5.7	3.7	2.0	.36
12	Keyport			7.3	3.7	3.6	
13	Manor, No. 298	18.1	1.81	7.4	4.1	3.3	.18
15	Kirvin, No. 6679	59.4	1.74	10.1	3.7	6.4	.11
14	Chester, No. 300	14.3	1.54	7.1	4.2	2.9	.20
16	....do			8.0	5.3	2.7	.20
9	Cecil, No. 6977	17.3	1.34	6.9	4.3	2.6	.15
10	....do			5.4	4.6	.8	.05
11	....do			6.4	3.8	2.6	.15
16	Nacogdoches, No. 9475	16.1	1.07	5.0	5.3	−.3	
14	Columbiana, No. 9804	48.0	.81	16.4	4.2	12.2	.25

[1] Se required per pot to reduce yield one-half. See text for full explanation.

The accuracy of the experimental figures is roughly indicated by the small differences in the toxicity values for quartz sand in different experiments. Apparently, the experimental figures in columns 5, and 6 are for the most part accurate within a milligram although certain determinations, such as those for the Marshall and Cecil soils in experiment 10, are probably less exact.

The significant features of the data in table 5 are: The general uniformity in the toxicity values for different soils; the very low values for the calculated specific effects of the different soil colloids; the lack of relation between the specific effects of the colloids and the silica-sesquioxide ratios of the colloids; and the fact that all soils except the Nacogdoches have higher toxicity values than quartz sand.

These results might be explained on the ground that a soil colloid has a slight capacity for forming a selenate compound which is insoluble and unavailable to the plant and that this capacity is not related to the silica-sesquioxide ratio. It is believed, however, that this is not the true explanation. It seems rather improbable that if the soil colloid has any capacity for forming an insoluble selenate it should be so small and should bear no relation to the silica-sesquioxide ratio. Also, it seems significant that soils containing widely different amounts of different kinds of colloid should have toxicity values so nearly alike.

Another explanation of the results is suggested by data, shown in table 4, on the movement of selenate towards the bottom of the pot during an experiment. The different distributions of sodium selenate in sand and soils evidently do not, in themselves account for the different toxicities found in these mediums. But these data on downward movement may be taken as indicating that mobility of the selenate in sand is greater than in soil and that mobility in the Marshall soil is greater than in the Cecil. Differences in mobilities might account for the different toxicities of selenate in the various mediums, for it is quite conceivable that toxicity of the selenate increases with its mobility in the medium of growth. A free movement of selenate into the area immediately contiguous to the roots, for instance, should promote absorption of selenate by the plant, since absorbed selenate would be rapidly renewed from other areas. The less mobility of selenate in soil than in sand may be due to differences in structure or it may be due to an attraction between the colloid and the selenate which is weaker than that existing where an insoluble compound is formed. In either case it would not be expected to parallel closely the chemical composition of the colloid.

The preceding explanation of the experimental results on the basis of mobility of the selenate is quite hypothetical, for we have no data regarding the movement of selenate into the area where absorption takes place and only presume that it is freer where the downward movement of the salt in the pot is freer. The explanation would account, however, for the less toxicity (higher half-toxicity values) of selenate in soils than in sand, the comparatively little variation in the toxicity values of different soils, and the lack of relation between the chemical composition of the colloid and its effect on the selenate.

The experimental results with whole soils, no matter how they are explained, show quite clearly that the toxicity of sodium selenate does not vary markedly in different soils. Both series of experiments, those with whole soils and the preceding ones with sand-soil mixtures,

indicate that if soil colloids have any specific effect on the selenate ion it is very small and does not parallel the silica-sexquioxide ratio.

SELENIUM CONTENT OF THE PLANTS

Many of the plants grown in the preceding experiments were analyzed for selenium, since it seemed possible that the selenium in the plant might furnish a better criterion of the soil's effect on selenate toxicity than the reduction in yield. Only the part of the plant above ground was analyzed. The roots doubtless contained some selenium, but Hurd-Karrer (*10*) has shown that practically all the selenate absorbed by certain plants is located in the part above ground.

Analyses were made in many cases of the crops grown with both 0.005 and 0.010 g of selenium per pot. Figure 2 summarizes the

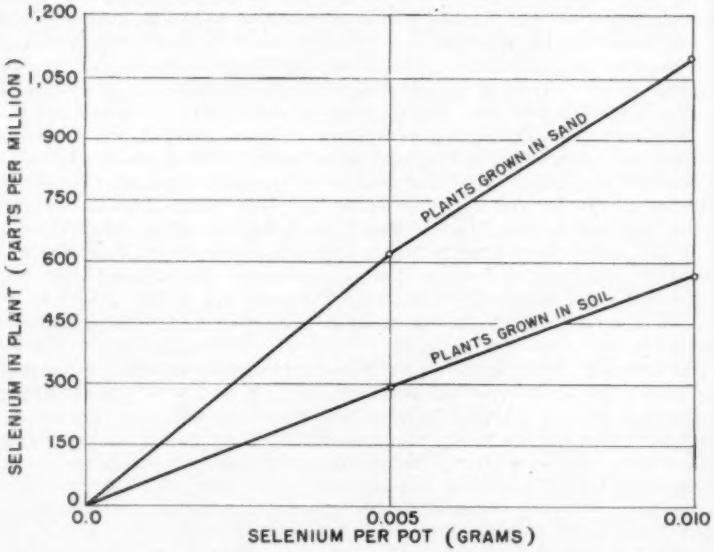

FIGURE 2.—Effect of increasing quantities of sodium selenate on the selenium content of millet.

results. The curve for quartz sand is an average of the results obtained with quartz sand in 5 experiments, Nos. 12 to 16, and the curve for soils is an average of the results obtained with 13 different soils in these experiments and in experiment 11. One of the results obtained with quartz sand and three of the results with soils gave curves differing widely from the average curves shown in figure 2, but for the most part individual curves were close to the average in form. The curves show that the selenium content of the plant above ground tends in general to increase in direct proportion to the quantity of sodium selenate applied. This holds for millet up to the point where the selenate is sufficient to inhibit yield appreciably, but may not hold for plants much more tolerant of selenate. Because of this direct proportionality between selenate applied and selenium in the plant, it was possible to calculate the selenium content of plants for selenate applications producing half injury.

If the selenium content of plants grown in quartz sand at different times is considered first, the data on plants grown in soil will be better understood. Tables 1 and 3 contain 11 different determinations of the quantity of sodium selenate reducing the yield of millet one-half in quartz sand and 9 determinations of the selenium content of the crops grown with an application of 0.005 g of selenium to the quartz sand. These data are brought together in table 6, together with figures calculated for the selenium content of the plants at one-half injury. The quartz sand series of experiments Nos. 9, 10, and 11 are not included in the table, since they are the same sand series that appear in experiments 5, 6, and 4, respectively. These experiments were run in pairs.

TABLE 6.—*Toxicity of sodium selenate in quartz sand as related to selenium in millet plants, determined in different experiments*

Experiment No.	Half-toxicity value Se required per pot to reduce yield one-half	Se in plants grown with 0.005 g of Se per pot	Calculated Se in plants at one-half injury point	Experiment No.	Half-toxicity value Se required per pot to reduce yield one-half	Se in plants grown with 0.005 g of Se per pot	Calculated Se in plants at one-half injury point
	Gram	*P. p. m.*	*P. p. m.*		*Gram*	*P. p. m.*	*P. p. m.*
1	0.0047	400	380	15	0.0037	750	550
2	.0054	----------	----------	16	.0053	630	640
3	.0043	----------	----------				
4	.0038	400	300	Average	.0044	560	480
5	.0043	590	510				
6	.0046	550	510	Standard deviation	.00056	111	105
12	.0037	460	340	Coefficient of variability	*Percent* 13	*Percent* 20	*Percent* 22
13	.0041	640	520				
14	.0042	620	530				

It will be seen that the data obtained in different experiments vary, the half-toxicity figures being more constant than figures representing the selenium content of the plants. Most of the differences in half-toxicity values obtained in different experiments are strictly experimental error, since they are of about the same magnitude as the probable error of one determination calculated from the crop weights of triplicated pots in a single experiment. For instance, the standard deviation of toxicity values in column 2, table 6, is 0.00056 g, and the probable errors of the last three values in this column, calculated from the probable errors of the average crop weights in an experiment, are, respectively, 0.0006, 0.0002, and 0.0005 g.

Since the variation in half-toxicity values determined at different times of the year is not appreciably greater than the variation expected of duplicate determinations conducted at the same time, it is obvious that the toxicity of sodium selenate is not appreciably affected by differences in light, temperature, etc., obtaining in an ordinary glass house at different times of the year. This conclusion is rather surprising, for the intensity and duration of sunlight differed widely between some of the experiments. In two experiments where growth conditions differed so much that the check pots receiving no selenate yielded crops weighing 4.03 and 2.09 g, the selenate applications producing half injury were, respectively, 0.0042 and 0.0041 g of selenium per pot.

The coefficients of variability show that the parts per million of selenium in plants grown with 0.005 g of selenium and the parts per

million of selenium in the plants at half injury are more variable than the selenium applications producing half injury. Analytical error could not account for this, so far as known, unless it be that selenium is lost from the plant on air drying. It would seem to follow, then, that the toxicity of absorbed selenate varies somewhat within the plant and that more selenate is taken up when conditions are such that it is less toxic. This conclusion, however, is far from certain. It may be that there was sufficient selenium in the roots, which were not analyzed, to equalize discrepancies in the selenium content of the plants above ground. It is also possible that the selenium content of the plant varies with the stage of maturity and that the plants were harvested at somewhat different stages of maturity. The stage of development at which the plants were cut (at jointing) was only approximately the same. In fact, it is somewhat of a question just what constitutes comparable stages of development in short- and long-day periods if the development of the plant varies with length of day. Until the factors responsible for the variable selenium content of the plants are established, the half-toxicity determination may be considered a better index of the soils' effect on selenate toxicity.

The selenium content of millet grown in different soils receiving 0.005 g of selenium per pot is shown in table 7. The table also shows the selenium content of plants grown in quartz sand in the same experiment, and the selenium application reducing the yield one-half in the soil.

TABLE 7.—*Se content of millet grown in soil and in quartz sand with sodium selenate applied at rate of 0.005 g Se per pot*

Experiment No.	Kind of soil	Half-toxicity value for soil (Se required per pot to reduce yield one-half)	Se content of plants grown—		Se content of soil-grown plants as percentage of Se content of quartz sand-grown plants
			In soil	In quartz sand in same experiment	
		Mg	*P. p. m.*	*P. p. m.*	*Percent*
14	Colby, No. 6842	6.0	350	620	56
10	Marshall, No. 8736	7.1	560	550	102
11	do	4.1	400	400	100
13	Spearfish, No. B1086	7.2	260	640	41
13	Clarion	6.1	260	640	41
14	Vernon, Nos. 6718–19	6.9	340	620	55
15	Muskingum, No. B407	7.4	230	750	31
15	Kirvin, No. 6678	5.7	180	750	24
12	Keyport	7.3	220	460	48
13	Manor, No. 298	7.4	250	640	39
15	Kirvin, No. 6679	10.1	360	760	48
14	Chester, No. 300	7.1	610	620	98
16	do	8.0	230	630	37
10	Cecil, No. 6977	5.4	570	550	104
11	do	6.4	240	400	60
16	Nacogdoches, No. 9475	5.0	340	630	54
14	Columbiana, No. 9804	16.4	130	620	21

Practically all the plants grown in soil have a lower selenium content than the corresponding plants grown in sand. The data indicate quite clearly, then, that sodium selenate is somewhat less toxic in nearly all soils than in quartz sand. The half-toxicity figures previously discussed led to the same conclusions, so in a general way the analytical data may be taken as supporting the growth data.

Although in general there is this agreement between toxicity values and selenium content, the variations in selenium content of plants from different soils do not follow the variations in toxicity values at all well, the correlation coefficient between the two sets of figures being −0.37. This was to be expected from the quartz-sand data in table 6, which showed that toxicity values obtained in different experiments were comparatively constant but selenium content of the plants varied. It seemed as though variations induced by growing the plants in six different experiments might be eliminated by expressing the selenium content of the soil-grown plants as percentages of the selenium content of the plants grown in quartz sand in the same experiment. The figures obtained in this way are given in the last column of table 7. These agree with the toxicity values only slightly better, the correlation coefficient being −0.44.

Neither the selenium content of the soil-grown plants (column 4, table 7) nor the relative selenium content (last column, table 7) shows an appreciable correspondence with the silica-sesquioxide ratios of the soil colloids or with the specific effects of the colloids given in table 5. The growth data in table 5, previously discussed, likewise failed to show an appreciable correspondence with the silica-sesquioxide ratios of the colloids.

In a general fashion, the selenium content of the plants supports the conclusions indicated by the half-toxicity values based on growth, but it does not seem to give any added information. The half-toxicity values, in being more closely reproducible, seem the more accurate criterion of selenate toxicity. Doubtless, with further investigation of the factors influencing the selenium content of the plant, these figures would be more valuable.

TESTS WITH PLANTS OTHER THAN MILLET

The data that have been considered were all obtained with millet. Had other plants been used, the figures would no doubt have been different, but the general results the same. Millet is more sensitive to selenate than many plants, but not exceptionally so. In a test with mustard with quartz sand (table 1, experiment 8), half injury was produced by 0.0051 g of selenium per pot from sodium selenate—a figure near the average for millet. Marquis wheat grown for 48 days (table 1, experiment 7), seems to be considerably more tolerant of selenate than millet. The half-toxicity figures obtained in quartz sand, in a Cecil soil-sand mixture, and in the Marshall soil (table 4) range from 0.0070 to 0.0078 g of selenium per pot (or about one and one-half times the figure for millet. The figure for wheat in the whole Cecil soil is about two-and-a-half times that for millet). The selenium content of the wheat plants above ground at one-half inquiry was about two times the average for millet in quartz sand.

GENERAL CONCLUSIONS

The foregoing experiments indicate that the toxicity of sodium selenate should vary little in different soils. Under comparable conditions of moisture and fertilization, most soils should tolerate about one and one-half times as much selenate as quartz sand, and an exceptional soil, such as the lateritic Columbiana, might stand three to four times as much as the sand. If the data obtained in 1-gallon pots

79780—38——2

are calculated to an acre 6 inches of soil, figures are obtained which may be incorrect by several hundred percent but are easy to comprehend. The application of 0.0044 g of selenium per pot, which reduced the yield of millet one-half in a pot of quartz sand, is equivalent to a little less than 1 part of selenium per million parts of soil (0.88 p. p. m.), and the application producing half injury in the average soil is a little less than 1½ parts of selenium per million, or about 3 pounds per acre. As a matter of fact, this figure of 1½ p. p. m. or 3 pounds per acre, is not fantastic. Byers (*3*) reports selenium absorption by certain plants from soils containing such quantities of selenium and an apparent effect on the flora. Moreover, boron applications of this general magnitude have been found distinctly injurious on some soils. It should be understood that selenate is only one of the forms in which selenium occurs in soils (*16*).

Apparently the toxicity of sodium selenate may vary more under different conditions in one and the same type of soil than under comparable conditions in different types of soil. With a low supply of sulphate in the soil, for instance, half as much selenate as the quantities mentioned above may produce notable injury. Variations in the vertical distribution of the selenate should also affect the toxicity in the field. The effect of variation in the water supply was not studied, but this may influence toxicity.

The soil colloids seem to have only a slight influence on the toxicity of sodium selenate. Experiments in sand-soil mixtures containing 1 percent of colloid gave no indication that the soil colloid reduces selenate toxicity. But in most whole soils the selenate was less toxic than in quartz sand, and this difference in toxicity presumably should be attributed to the colloids in the soils. It does not seem that the small reduction in selenate toxicity in whole soils is due to a specific reaction between colloid and selenate, resulting in a compound unavailable to the plant. It seems rather that the reduced toxicity is due to a more general effect of the colloids on distribution or movement of the selenate in the soil medium.

SUMMARY

This investigation deals with the effects of soil colloids on the toxicity of sodium selenate to millet, as determined by vegetative experiments in pots. The measure of toxicity employed is the quantity of selenate required to reduce yield one-half.

Experiments in quartz sand, in soil, and in sand-soil mixtures show that the toxicity of sodium selenate is not appreciably affected by phosphate fertilization, but is affected by the vertical distribution of selenate in the pot and by sulphate fertilization. When the sulphate application is high, the selenate application needed to reduce yield one-half may be two to three times that needed when the sulphate supply is adequate only for maximum yield.

With a constant sulphate fertilization, sodium selenate is as toxic in sand-soil mixtures containing 1 percent of different soil colloids as in pure quartz sand, but is somewhat less toxic in whole soils. It does not seem that the small reduction in selenate toxicity in whole soils, as compared with quartz sand, is due to a specific reaction between colloid and selenate, resulting in a compound unavailable to the plant. The reduction in toxicity seems rather to be due to a

general effect of the colloids, possibly on movement of selenate in the soil medium. Differences between the toxicities of selenate in sand and in 14 soils bear no relation to the silica-sesquioxide ratios of the soil colloids.

The quantity of selenate required to reduce yield one-half is unaffected by the different growth conditions obtaining in an ordinary greenhouse at different times of the year. The selenium content of the plants at half injury is more variable than the half-toxicity values.

Marquis wheat grown for 48 days requires one and one-half times as much selenate to reduce yield one-half as millet grown to the jointing stage, and at half injury the part above ground contains about twice as much selenium.

The data obtained in 1-gallon pots indicate that about one and one-half parts per million of selenium as selenate, or 3 pounds per acre 6 inches, should be distinctly injurious to millet in most soils. This calculation from a pot to an acre is of course not reliable, but the figure is in harmony with field observations.

The preceding conclusions apply only to selenium in the form of sodium selenate. In work now in progress quite different results are being obtained with sodium selenite.

LITERATURE CITED

(1) Brown, Irvin C., and Byers, Horace G.
1935. The chemical and physical properties of dry-land soils and of their colloids. U. S. Dept. Agr. Tech. Bull. 502, 56 pp.

(2) Byers, Horace G.
1935. Selenium occurrence in certain soils in the United States, with a discussion of related topics. U. S. Dept. Agr. Tech. Bull. 482, 48 pp., illus.

(3) ———
1936. Selenium occurrence in certain soils in the United States, with a discussion of related topics. Second report. U. S. Dept. Agr. Tech. Bull. 530, 79 pp., illus.

(4) ——— Alexander, Lyle T., and Holmes, R. S.
1935. The composition and constitution of the colloids of certain of the great groups of soils. U. S. Dept. Agr. Tech. Bull. 484, 39 pp.

(5) Gile, Philip L.
1933. The effect of different colloidal soil materials on the efficiency of superphosphate. U. S. Dept. Agr. Tech. Bull. 371, 50 pp., illus.

(6) ———
1936. The effect of different colloidal soil materials on the toxicity of calcium arsenate to millet. Jour. Agr. Research 52: 477–491, illus.

(7) Gile, P. L., Middleton, H. E., Robinson, W. O., Fry, W. H., and Anderson, M. S.
1924. Estimation of the colloidal material in soils by adsorption. U. S. Dept. Agr. Bull. 1193, 42 pp.

(8) Hurd-Karrer, Annie M.
1934. Selenium injury to wheat plants and its inhibition by sulphur. Jour. Agr. Research 49: 343–357, illus.

(9) ———
1935. Factors affecting the absorption of selenium from soils by plants. Jour. Agr. Research 50: 413–427, illus.

(10) ———
1937. Comparative toxicity of selenates and selenites to wheat. Amer. Jour. Bot. 24: 720–728, illus.

(11) MIDDLETON, H. E., SLATER, C. S., and BYERS, HORACE G.
1932. PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS. U. S. Dept. Agr. Tech. Bull. 316, 51 pp.

(12) ———
SLATER, C. S., and BYERS, H. G.
1934. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS—SECOND REPORT. U. S. Dept. Agr. Tech. Bull. 430, 63 pp., illus.

(13) MITSCHERLICH, EILH. ALFRED.
1913. BODENKUNDE FÜR LAND- UND FORSTWIRTE. Aufl. 2, vollständig umgearb., 317 pp., illus. Berlin.

(14) ROBINSON, W. O., and HOLMES, R. S.
1924. THE CHEMICAL COMPOSITION OF SOIL COLLOIDS. U. S. Dept. Agr. Bull. 1311, 42 pp.

(15) SLATER, C. S., HOLMES, R. S., and BYERS, H. G.
1937. TRACE ELEMENTS IN THE SOILS FROM THE EROSION EXPERIMENT STATIONS, WITH SUPPLEMENTARY DATA ON OTHER SOILS. U. S. Dept. Agr. Tech. Bull. 552, 24 pp.

(16) WILLIAMS, K. T., and BYERS, H. G.
1936. SELENIUM COMPOUNDS IN SOILS. Indus. and Engin. Chem. 28: 912–914.

(17) ——— and LAKIN, H. W.
1935. DETERMINATION OF SELENIUM IN ORGANIC MATTER. Indus. and Engin. Chem., Analyt. Ed. 7: 409–410.

GROWTH SUBSTANCE AND THE DEVELOPMENT OF CROWN GALL[1]

By S. B. LOCKE, *research assistant in plant pathology*, A. J. RIKER, *professor of plant pathology*, and B. M. DUGGAR, *professor of botany and plant pathology, Wisconsin Agricultural Experiment Station.*[2]

INTRODUCTION

Advances made recently in the study of plant growth substances and their function in normal growth have raised the question of their possible role in atypical and pathological growth and specifically in the gall development induced by *Phytomonas tumefaciens* (Smith and Town.) Bergey et al.

A suggestion of their presence was first given by the marked epinasty of leaf petioles in plants inoculated with the crown gall organism. Other responses, including the initiation of adventitious roots, stimulation of cambial activity, inhibition of bud development, and delayed abscission of senescent leaves, strengthened this suggestion. The relation of these responses to growth substances in general are discussed by Boysen-Jensen (*3*).[3] Most of these phenomena have doubtless been frequently observed by those studying crown gall, but so far as the writers are aware only Němec (*25*) has interpreted any of them in relation to growth substances. Some of the literature providing a background for this problem is very briefly considered.

Epinasty of leaf petioles in tomato, resulting from the rapid elongation of cells on the upper side of the petioles, has been induced by beta-indole-acetic acid, and by numerous other compounds (*7*, *8*, *10*, *11*).

Initiation of adventitious roots in response to treatment with various growth substances has been frequently reported. Unsaturated hydrocarbon gases (*44*, *45*, *46*), pure auxins (*40*, cf. *43*), beta-indole-acetic acid (*39*), and certain other synthetic compounds (*47*) were demonstrated to stimulate the production of root initials. Initiation of roots in conjunction with crown gall was apparently observed early in the history of the disease (*33*) and was confirmed later (*5*, *25*). However, this is not to be confused with the hairy root condition caused by *Phytomonas rhizogenes* R. B. W. K. S.

Growth substances were found (*37*) to stimulate the cambium. Such stimulation was also obtained with beta-indole-acetic acid (*36*). Recently (*1*) cambial activity has been found to begin at the terminal buds and to progress basipetally following the movement of the growth substance. Stimulation of the cambium in the vicinity of crown gall tissue has also been noted (*26*, *32*).

Apical dominance and inhibition of axillary buds was at first attributed to a specific retarding substance (*34*, *35*) which was later considered to be identical with growth substance (*41*, *42*). Inhibition of axillary buds has been obtained with beta-indole-acetic, beta-indole-

[1] Received for publication November 12, 1937; issued July 1, 1938. This work was supported in part by the special research fund of the University of Wisconsin and by the International Cancer Research Foundation.

[2] The writers are indebted to Eugene Herrling for preparing the photographs.

[3] Italic numbers in parentheses refer to Literature Cited, p. 37.

propionic (*11, 39*), and several other indole acids (*2*). The effect of crown gall upon bud development has been disputed. Smith (*29, 30, 31*) obtained leafy galls by inoculating internodes and axillary buds with crown gall bacteria, and explained it by stimulation of cells already possessing the potentiality of shoot formation. However, Levine (*18, 19, 20*) obtained opposing results and observed an inhibitive effect on the leaf-notch meristems of *Bryophyllum*. Němec (*25*) observed that inoculation of chicory root cuttings on the upper cut surface prevented the usual formation of shoots there. He concluded that growth substance produced by the bacteria was responsible for this effect.

Abscission of leaf petioles commonly follows closely after the deterioration or removal of the leaf blades which they support. Laibach (*13*) found that orchid pollen prevented the falling off of petioles, and he ascribed this effect to growth substance. LaRue (*17*) obtained inhibition of petiole abscission in *Coleus* with growth substances from leaves, pollen, and urine, and with beta-indole-acetic acid.

Growth substances have been found to stimulate the development of "callus," an effect which approaches the characteristic early consequence of inoculation with *Phytomonas tumefaciens*. Laibach and associates (*14, 15, 16*) stimulated callus development on stems of *Coleus*, and *Tradescantia* with extracts of pollen and of urine and also by applying a paste of beta-indole-acetic acid in lanolin to decapitated plants of *Vicia faba* Linn. Brown and Gardner (*6*) and Link, Wilcox, and Link (*22*) have also stimulated growth with substances isolated from crown gall cultures and applied to decapitated plants of *Phaseolus vulgaris* Linn. These authors produced similar proliferations with beta-indole-acetic acid. The histological developments produced by application of beta-indole-acetic acid resemble closely many of those associated with crown gall (*12*). Following Smith (*30*), Riker and Berge (*27*) list numerous other chemical agents capable of stimulating cell division locally and say, "The great diversity of materials reported to cause stimulation suggests that irritation or injury induced by them, which is apparently a common characteristic, is more important than the nature of the substance." Levine and Chargaff (*21*) recently tested several chemical fractions of crown gall bacteria and found the phosphatide fraction the most active in producing cell proliferations. It seems uncertain at present which, if any, of the chemicals listed belong to the group of growth substances under consideration here.

From these and related investigations it appeared desirable to examine the relation between the effects of growth substance and the development of crown gall. The work here reported falls under four headings: (1) A survey of responses to inoculation indicating the presence of growth substance in abnormal amount, (2) estimation of amount of growth substance in inoculated and uninoculated tissues, (3) production of growth substance by bacteria in culture, and (4) determination of the effect of an external source of growth substance upon the proliferation of tissues inoculated with an attenuated strain of the crown gall organism. The activities of attenuated and virulent strains have been compared when feasible. A preliminary report (*23*) has already appeared.

MATERIALS AND METHODS

Virulent (A6) and attenuated (A6–6), single-cell sister crown gall cultures described by Hendrickson, Baldwin, and Riker (*9*) were em-

ployed. Numerous inoculations have been made into tomato, *Sedum*, *Bryophyllum*, and *Kalanchoe*. The attenuated culture has consistently induced some proliferation, although it is very slight on tomato and is always less than that induced by the virulent strain on the other plants.

Lycopersicum esculentum Mill. was employed because of ease of propagation and the short time required for development of galls following inoculation. *Bryophyllum pinnatum* (L.) Kurtz and *Kalanchoe diagremontiana* Hamet et Perrier were used because they produce relatively large galls with the attenuated strain and have more completely dormant axillary buds than the tomato.

Avena coleoptile tests were made in a dark room at 23° to 25° C., with over 90 percent relative humidity. The oats, supplied by Dr. H. L. Shands, were of a genetically stable variety designated "State's Pride, Pedigree 7–7."[4] When the coleoptile reached a length of 2.5 to 3.0 cm they were ready for use. The first leaf was pulled almost out and cut off a few millimeters above the coleoptile tip. The seedlings were placed in individual holders with their roots in water. The test itself was carried out in two ways.

For detecting growth substance in inoculated tissues, Went's method *(43a)* was used. Tomato seedlings (about 10 cm tall) were inoculated at three points on the stem by means of needle punctures. Control plants received sterile needle punctures. After the desired interval of time 1-cm sections, each including an inoculation or control puncture, were cut from the stems and placed upright on blocks of 3-percent agar having the dimensions 1.5 by 4 by 4 mm. After 2.5 hours the sections were removed and the agar blocks cut into four equal parts. These were placed unilaterally on decapitated oat coleoptiles. The curvatures produced in 2.5 hours were recorded and translated into "plant units" (the amount of growth substance applied in one agar block to give an angle of 1°, cf. (*3*)). Based upon the size of blocks employed in these experiments, one plant unit is equal to 0.3 *Avena* unit.

A second method, patterned after that of Brecht (*4*), was used for the detection of growth substance in culture fluids. The acidified culture was extracted several times with chloroform, the combined extracts equaling twice the volume of the culture. The chloroform was then evaporated off and the residue taken up in a small amount of water. An equal weight of lanolin was then mixed with the water to form a stiff paste. This was applied along one side of decapitated coleoptiles for their full length. Readings on the curvatures produced were made over a 24-hour period.

In some of the experiments beta-indole-acetic acid and beta-indole-propionic acid in the form of lanolin-water emulsions were used. Low concentrations of chemicals were mixed with the water before making the emulsion. High concentrations were first mixed with the lanolin.

RESPONSES OF INOCULATED PLANTS SUGGESTING THE PRESENCE OF GROWTH SUBSTANCE

EPINASTY OF LEAF PETIOLES

Epinasty in the lower leaves of young tomato plants bearing several well-developed galls was studied in a preliminary experiment. Two tomato plants about 15 cm tall were inoculated at five points along

[4] This variety gave approximately the same sensitivity as the Victory oats generally employed in plant hormone work.

the stem by means of needle punctures, one with the virulent strain, and one with the attenuated strain. A third received sterile punctures. Nineteen days later galls were evident on the plant inoculated

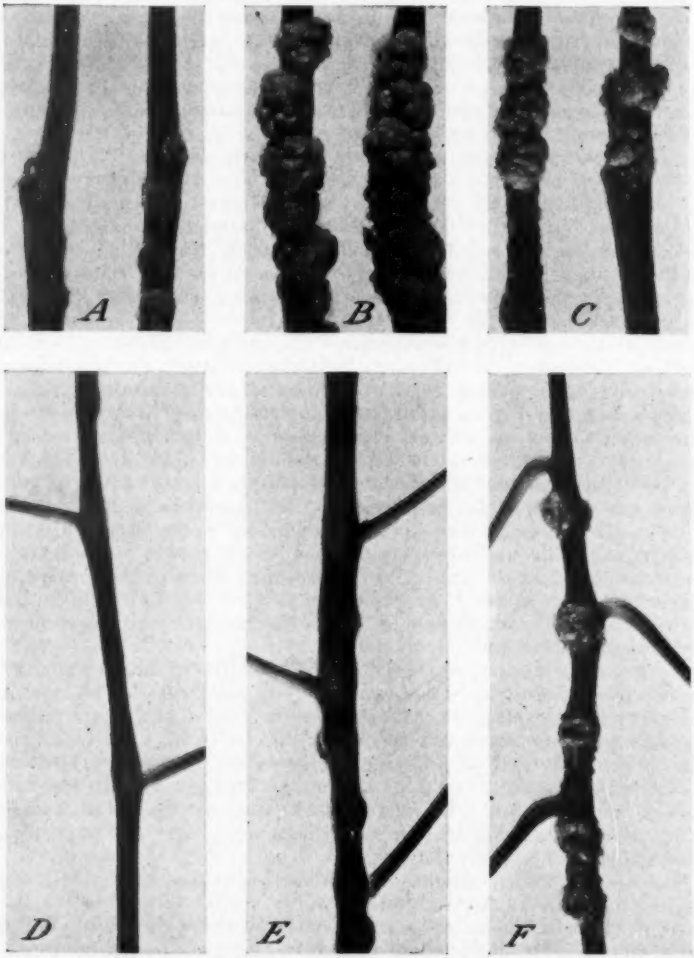

FIGURE 1.—Stimulation of tissues inoculated with the attenuated crown gall bacteria, and production of epinasty following inoculation with the virulent strain. Decapitated tomato plants six weeks after inoculation: *A*, Three control punctures above and three attenuated-strain inoculations below; *B*, three virulent-strain inoculations above and three attenuated-strain inoculations below; *C*, three virulent-strain inoculations above and three control punctures below. Intact tomato plants 19 days after inoculation at five points along the stem: *D*, Plant with control punctures; *E*, inoculated with the attentuated strain; *F*, inoculated with the virulent strain.

with the virulent strain, and the petioles originating near the galls were bent sharply downward (fig. 1, *F*). The plant inoculated with the attenuated strain (fig. 1, *E*) bore small swellings at the points of

inoculation and the petioles originating near them maintained approximately the same angle as those of the control plant (fig. 1, *D*).

Similar results have been observed in a considerable variety of experiments. The results from two representative trials are given in table 1. Here it appears that, while the virulent strain increased epinasty greatly in 14 days, the attenuated strain had no apparent influence upon it.

TABLE 1.—*Epinasty of tomato petioles following crown gall inoculations* [1]

Inoculant	Extent of epinasty after number of days indicated					
	Trial No. 1			Trial No. 2		
	0 days	7 days	14 days	0 days	7 days	14 days
	Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
Uninoculated	57	66	76	59	69	75
Attenuated strain	56	65	74	62	67	65
Virulent strain	63	79	117	64	81	107

[1] Plants 6 inches high were inoculated 4 or 5 times, once between each node. Controls received sterile punctures. The degrees given are the averages of 30 axillary angles, 5 on each of 6 plants.

It was noted on numerous occasions that tomato plants bearing a single inoculation with the virulent strain exhibited very little epinasty. This suggested a relation between the number of inoculations and the degree of epinasty produced, which was tested on four lots of five plants each, bearing different numbers of inoculations. The results in table 2 show that, with an increase in the number of inoculations, there was in general an increase in the amount of epinasty induced. This is partly because more petioles were near galls on plants inoculated in a greater number of internodes, but not entirely, since the petioles immediately below the uppermost inoculation showed greater epinasty when additional inoculations were made in the internodes farther down the stem.

TABLE 2.—*Increase in epinasty of tomato petioles following increase in number of inoculations with the virulent strain* [1]

Inoculations (number)	Extent of epinasty shown by petioles in position indicated			Average axillary angle
	First	Second	Third	
	Degrees	*Degrees*	*Degrees*	*Degrees*
1	90	84	90	88
2	90	105	103	99
4	106	104	101	103
8	110	113	125	116

[1] The plants were inoculated once in each of 1, 2, 4, and 8 internodes respectively, beginning at the top (first) and proceeding downward. The degrees given are averages of corresponding axillary angles of 5 plants 3 weeks after inoculation.

INITIATION OF ADVENTITIOUS ROOTS

The initiation of roots in conjunction with crown gall development was observed on several species. Figure 2 shows *Kalanchoe* plants 1 month after treatment. No roots appear on the control plant

(*D*) or on the plant inoculated with the attenuated strain (*E*). On the plant inoculated with the virulent strain (*F*), numerous adventi-

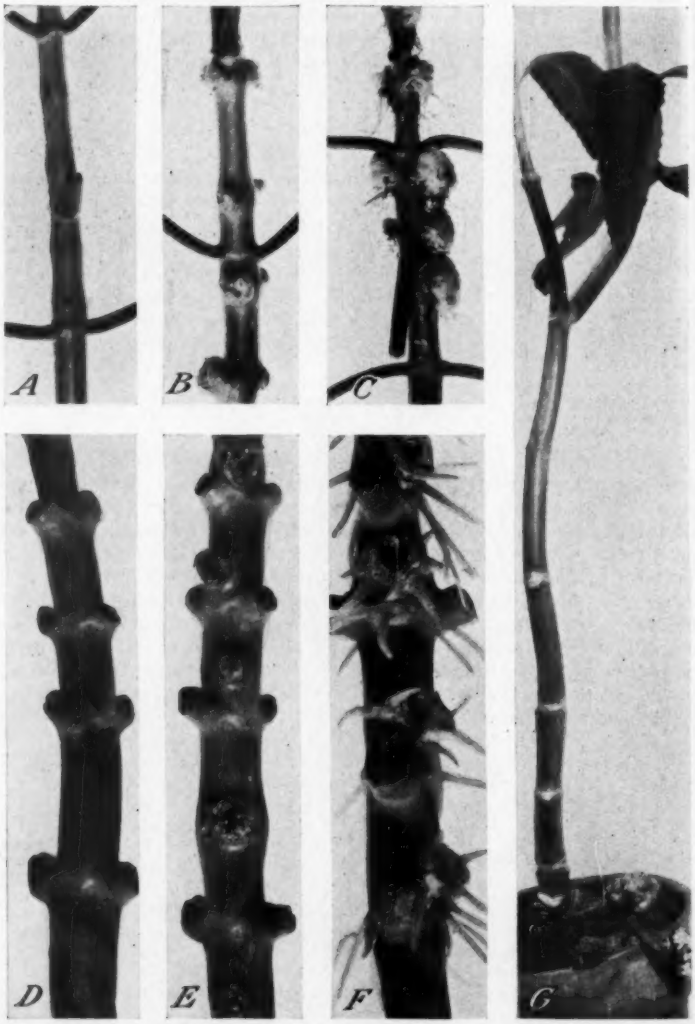

FIGURE 2.—Root production and delay of leaf abscission resulting from inoculations with crown gall bacteria. *Bryophyllum pinnatum* plants: *A*, Uninoculated; *B*, inoculated with the attenuated strain; *C*, inoculated with the virulent strain. *Kalanchoe diagremontiana* plants: *D*, Uninoculated; *E*, inoculated with the attenuated strain; *F*, inoculated with the virulent strain. *Kalanchoe* leaf (*G*) several months after inoculation with the virulent strain; leaves of eight younger nodes have been shed while inoculated leaf at the base remains firmly attached.

tious roots developed about the inoculations, sometimes at a distance from the inoculated tissue. Likewise in figure 3, *A*, where a decapi-

tated plant was inoculated on the cut surface, the roots appeared on the internode several centimeters below the gall. Such results have been obtained with this host repeatedly. These roots are not to be confused with those arising from the hairy root organism, *Phytomonas rhizogenes*.

Root initiation was obtained when *Bryophyllum* was inoculated with the virulent strain, but there was little subsequent development. Figure 2 shows three plants approximately 1 month after treatment. Roots appeared abundantly from the lower margins of the galls induced by the virulent strain (*C*), while none appeared about the swellings induced by the attenuated strain (*B*) or on the control plants (*A*).

Root initiation on inoculated tomato plants was quite abundant. In one experiment plants about 12 cm tall were inoculated in the first five internodes by means of a needle puncture, six with the virulent strain and six with the attenuated strain. Six more received sterile punctures. The numbers of root primordia appearing on the stems were recorded at the time of inoculation and after 1 and 2 weeks had passed. After 2 weeks normal root initiation on the stems tends to equalize differences between inoculated and uninoculated plants. The results of two representative trials appear in table 3. Plants inoculated with the virulent strain produced many more root primordia than either the controls or those inoculated with the attenuated strain.

TABLE 3.—*Initiation of root primordia on stems of tomato plants inoculated with crown gall bacteria* [1]

Inoculant	Root primordia on stems after number of days indicated					
	Trial No. 1			Trial No. 2		
	0 days	7 days	14 days	0 days	7 days	14 days
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Uninoculated	0	2	6	0	0	6
Attenuated strain	0	2	5	0	1	21
Virulent strain	1	13	44	0	14	61

[1] Plants were inoculated 4 or 5 times, once for each internode. The figures given are the average number of root primordia appearing on 6 plants.

STIMULATION OF THE CAMBIUM

Cambial stimulation was studied in tomato plants which were decapitated when they were about 20 cm tall at a point where the stem was about 3 mm in diameter. Lots of four plants each were thus prepared. To the cut stem tip of one lot the virulent strain was applied, to that of another the attenuated strain was applied, and that of a third was left untreated. Two weeks later gall tissue was visible on the plants inoculated with the virulent strain while none was apparent on the others. The internode below the gall had increased in thickness at about the same rate as the corresponding internodes of whole plants. However, on the other plants the internode below the point of decapitation remained about the same in diameter as when the cut was made. One month after inoculation the stem thickness

was measured, two readings being taken at right angles to each other. The average of four pairs of readings was 3.3 mm for the uninoculated plants, 4.5 mm for those inoculated with the attenuated strain, and

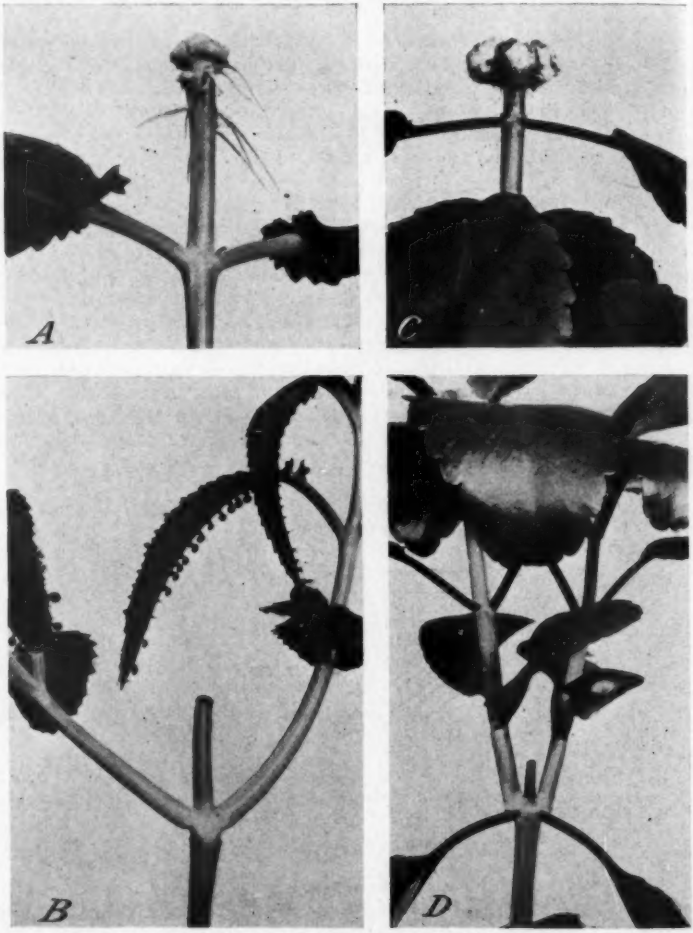

FIGURE 3.—Inhibition of axillary buds and stimulation of cambial activity resulting from inoculation with crown gall bacteria. *A*, Decapitated *Kalanchoe* plant inoculated on the cut surface with the virulent strain. Axillary buds have failed to develop and the decapitated internode has increased in thickness. *B*, Decapitated *Kalanchoe* plant, uninoculated, showing shoots which have developed from axillary buds of the uppermost node. (The leaves have been shed from this node.) *C* and *D*, Decapitated *Bryophyllum* plants treated like the plants in *A* and *B*, respectively, and showing similar results. Photographed 7 weeks after treatment.

6.0 mm for those inoculated with the virulent strain. Similar results were obtained in a second trial. Stimulation of cambium in decapitated internodes of *Kalanchoe* and *Bryophyllum* also was obtained following inoculation with the virulent strain of crown gall bacteria

(fig. 3). Sliding-microtome sections of the *Kalanchoe* plants showed a solid cylinder of secondary xylem in the inoculated plant but apparently no secondary xylem in the uninoculated plant (fig. 4). Freehand sections of both sets of material revealed that, although some

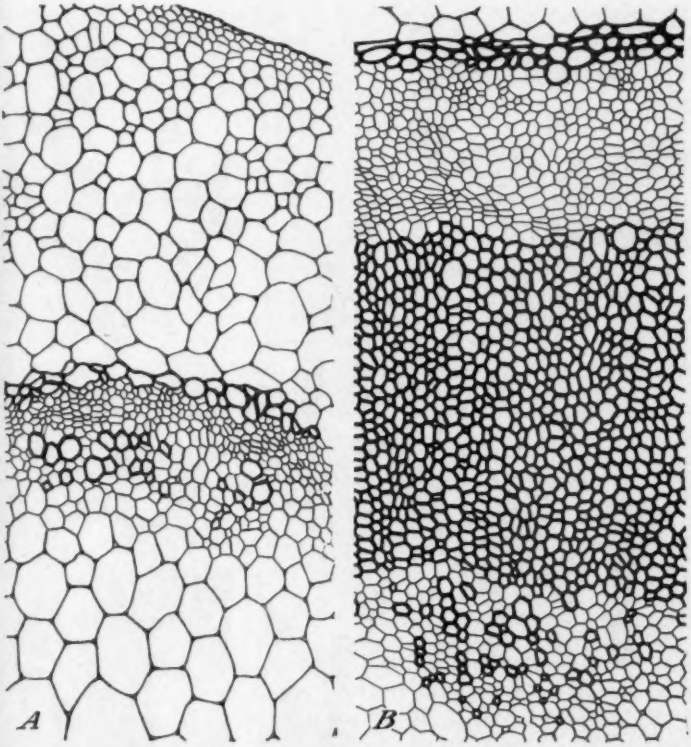

FIGURE 4.—Camera-lucida drawings of portions of vascular cylinders of decapitated *Kalanchoe* plants 7 weeks after treatment: *A*, an uninoculated plant showing no secondary xylem; *B*, a plant inoculated on the cut surface with the virulent strain of crown gall bacteria, showing a broad band of heavy-walled secondary xylem. These sections were made a few millimeters below the tips of plants *A* and *B* of figure 3.

increase in size of the pith cells had occurred, the greater part of the increase in thickness resulted from activity of the cambium.

INHIBITION OF BUD DEVELOPMENT

With *Kalanchoe* and *Bryophyllum* the inhibition of development of the axillary buds was clear-cut in repeated trials with plants decapitated and inoculated with the virulent strain on the cut surface (fig. 3, *A*, *C*). In plants decapitated but not inoculated (fig. 3, *B*, *D*) the axillary buds of the uppermost remaining node developed into shoots.

Inhibition of axillary buds following decapitation was similarly obtained in the vicinity of inoculations in repeated trials with tomato, but only when removal of the part of the plant above the inoculations was delayed until galls were well developed.

Evidence of inhibition of development of adventitious buds was obtained with decapitated tomato plants. In the first trial three lots of eight plants each were employed. Plants inoculated on the cut surface with the virulent strain developed abundant gall tissue

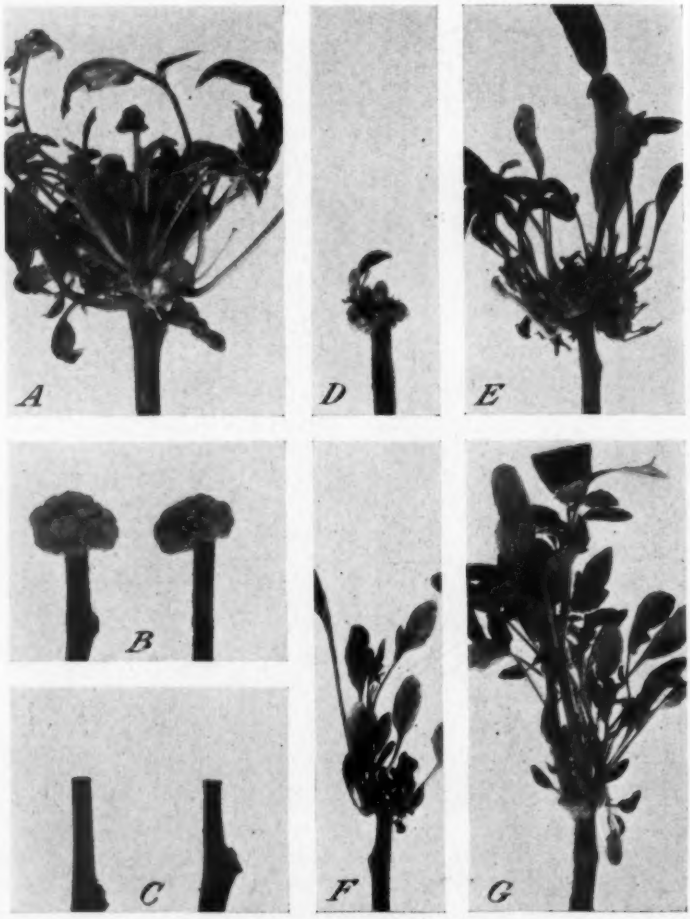

FIGURE 5.—Inhibition of development of adventitious shoots on decapitated tomato plants inoculated with virulent crown gall bacteria. Axillary buds not removed: *A*, Inoculated with the attenuated strain; *B*, inoculated with the virulent strain; *C*, uninoculated. Axillary buds removed: *D*, Inoculated with the virulent strain; *E*, inoculated with the attenuated strain; *F*, uninoculated; *G*, inoculated with a mixture of the virulent and attenuated strains.

but no adventitious buds (fig. 5, *B*). Plants inoculated on the cut surface with the attenuated strain developed numerous adventitious buds and shoots and, later, large masses of green gall tissue at the cut surface (fig. 5, *A*). Uninoculated plants developed no callus or adventitious buds at the cut surface (fig. 5, *C*.) A second trial was

made on decapitated plants from which, in addition, all axillary buds had been removed. This treatment resulted in a greater tendency to produce adventitious buds, which appeared on all of the plants. However, on plants inoculated with the virulent strain these remained very small (fig. 5, *D*). On plants inoculated with the attenuated strain large shoots and later large masses of green gall tissue developed (fig. 5, *E*). Uninoculated plants developed shoots but no gall tissue (fig. 5, *F*). Plants inoculated with a mixture of virulent and attenuated strains produced two kinds of gall tissue, one pale and free of buds and the other green and bearing numerous adventitious shoots (fig. 5, *G*).

The effect of the attenuated strain on development of axillary buds was not determined on *Kalanchoe* and *Bryophyllum* by the above method because inoculations made on the cut surfaces of decapitated plants consistently failed to develop galls. Stem-puncture inoculations, however, produce good-sized galls on these plants, and it has been observed that axillary buds in the vicinity of the galls frequently develop into short shoots even when the top of the plant is not removed. This has never been observed in the dozens of plants inoculated with the virulent strain during the course of this study. These results indicate that the attenuated strain not only fails to inhibit bud development but even stimulates it.

The mechanism of this stimulation is not known. Among the possibilities are (1) a specific shoot-stimulating substance, (2) isolation of the axillary buds from influence of the apical bud by distortion of conducting tissues, and (3) removal of growth substance or other growth inhibitors by the inoculated tissues.

DELAY OF PETIOLE ABSCISSION

Delay of abscission of leaves inoculated with crown gall was conspicuous in *Kalanchoe*. In one case a lower leaf bearing two galls about 1.5 cm in diameter persisted while the plant had increased in height and had shed the leaves of eight higher nodes (fig. 2, *G*).

Similar effects were observed on tomato. For example, six plants each were inoculated with the virulent and attenuated strains by means of shallow needle punctures on the upper surface of several petioles just below the first leaflet. Control plants were treated similarly, using a sterile needle. Two weeks after inoculation swellings were visible at the inoculated points. At this time the parts distal to the swellings were cut off. Virulent and attenuated strains of the crown gall bacteria were in this case about equally effective in inhibiting abscission (table 4).

TABLE 4.—*The inhibiting effect of crown gall on abscission of leaf petioles in tomato* [1]

Inoculant	Treated petioles	Treated petioles remaining attached after—			
		14 days	19 days	33 days	43 days
	Number	*Percent*	*Percent*	*Percent*	*Percent*
Uninoculated	28	64	25	0	0
Attenuated strain	64	100	100	67	39
Virulent strain	31	100	93	58	35

[1] Petioles were inoculated just below the first leaflet 2 weeks previous to removing the distal portion of the leaf.

The effect of inoculation with crown gall bacteria on petiole abscission in *Bryophyllum* was tested on lots of seven plants each. One petiole of five or six pairs on each plant was inoculated at the base of the leaf blade. The other member of each pair received a control puncture. Six weeks after inoculation the leaf blades were removed by severing just above the point of inoculation. At this time small galls (2 to 5 mm) had developed from the inoculations made with the virulent strain. Inoculations with the attenuated strain had produced swellings only slightly larger than those on the 61 control petioles. Three days after the removal of the leaf blades all of the control petioles had been shed. Of the 32 petioles inoculated with the attenuated strain 8 remained attached. All 29 of the petioles inoculated with the virulent strain remained attached and were still attached after 2 weeks. At this time two additional petioles inoculated with the attenuated strain had been shed. In this case the virulent strain was more effective than the attenuated strain in preventing abscission. Other trials on *Bryophyllum* gave similar results.

DETERMINATION OF GROWTH SUBSTANCE IN INOCULATED TISSUE

Although the foregoing experiments furnish strong evidence for the production, either by the bacteria or by the host cells, of growth substance in inoculated tissues, more direct evidence was sought. Went's *Avena* test was employed as described in the section on materials and methods.

In one trial determinations were made on one inoculated and one uninoculated tomato seedling 3 days after inoculation, and on similar plants, 6 and 9 days after inoculation. The amount of growth substance detected, expressed in plant units, appears in table 5. Another trial was made in which three seedlings were used for each determination after intervals of 3, 6, 8, and 10 days. The results were similar to those of the first trial. More growth substance was obtained from inoculated than from the uninoculated tissue.

Unsuccessful trials were made by means of Went's *Avena* test with tissue from well-developed galls. No significant amount of growth substance was detected. Likewise, attempts to extract large crown galls with chloroform and alcohol to secure a growth substance have failed. The details are omitted because of the negative results.

TABLE 5.—*Production of growth substance in tomato seedlings inoculated with crown gall bacteria* [1]

Days after inoculation	Production of growth substance per seedling of—	
	Uninoculated plants	Inoculated plants
	Plant units [2]	*Plant units* [2]
3	53	86
6	16	143
9	17	276

[1] Determinations were made by means of Went's *Avena* test on 3 1-cm stem sections from a single seedling, each bearing an inoculation with the virulent strain or a control puncture.

[2] The amount of growth substance applied in 1 agar block to give an angle of 1° (equal to 0.3 *Avena* unit in this case; thus 276 plant units equal 83 *Avena* units).

PRODUCTION OF GROWTH SUBSTANCE IN CULTURE

Growth-substance production by crown gall bacteria in media was studied in a preliminary way. Such substances were found in cultures on peptone medium containing tryptophane by Brown and Gardner (*6*) and by Link, Wilcox, and Link (*22*). In view of reports of similar action by various other micro-organisms (*3*) it seemed desirable to make a comparison between pathogenic and nonpathogenic organisms with respect to this character.

Several preliminary experiments have been completed with the virulent and attenuated strains of crown gall bacteria and with a single-cell culture of *Bacillus radiobacter* Beij. and Van Deld., in beef broth containing peptone and tryptophane. Growth substance was extracted from the cultures with chloroform, recovered by evaporation, and incorporated into a lanolin-water paste. The activities of the various preparations were tested on oat coleoptiles after Brecht's method (14). Some growth substance was obtained from cultures of all three organisms and also from the unseeded medium. Only about four times as much was obtained from the virulent crown gall cultures as from the nonpathogenic *B. radiobacter* culture. No consistent difference in the production of growth substance has thus far been established between the virulent and attenuated cultures of crown gall bacterial.

EFFECT OF GROWTH SUBSTANCE ON TISSUE INOCULATED WITH THE ATTENUATED STRAIN

The relation of growth substance to the development of tissue about inoculations with the attenuated culture was studied. It appeared that, if the failure of the attenuated strain of crown gall bacteria to induce galls on tomato were associated with the absence of growth substance the application of growth substance should result in increased proliferation. Tests were made with growth substance from several sources.

GROWTH SUBSTANCE FROM THE EXPANDING FOLIAGE OF THE HOST

When inoculated into tomato plants the attenuated strain may have some effect, as already seen in figure 1, *E*. Swellings were induced that were distinguishable from those resulting from control punctures, possibly owing to the growth substance which normally originates in the expanding foliage of the plant, which passes downward into the inoculated tissues, and there increases proliferation. To test this suggestion, three inoculations were made with the attenuated strain in each of four decapitated and four whole tomato plants. Control plants received sterile punctures. Ten days later inoculations on decapitated plants were indistinguishable from control punctures while those on whole plants showed swellings distinctly greater than those resulting from control punctures. Similar results were obtained in a second trial on tomato employing lots of eight plants each. In this trial slight swellings appeared after 6 weeks on some of the decapitated plants, but the largest of these (fig. 1, *A*) were smaller than the smallest of those on the whole plants. In some cases the inoculations with the attenuated culture on decapitated plants was little, if any, larger than the control puncture.

79780—38——3

The effect of expanding foliage on inoculations with the attenuated strain was also tested on *Bryophyllum*. Five plants ranging from 12 to 20 cm in height were inoculated with this strain five times in the upper part of the stem. Five more were inoculated in the same way but after they had been decapitated and defoliated in the region inoculated. Galls developed from all of the inoculations in the whole plants, while in the decapitated plants gall development took place in less than half of the cases and was slower. The stimulating effect of the foliage was quite evident.

GROWTH SUBSTANCE FROM GALLS INDUCED BY THE VIRULENT STRAIN

Experiments were made to determine the effect of growth substance from active galls upon tissues inoculated with the attenuated strain. Three lots each containing six tomato plants about 25 cm high were decapitated and the leaves and axillary buds of the two nodes next below were removed, leaving a bare stub approximately 10 cm in length. Six puncture treatments were made approximately 1 cm apart in the denuded stubs as follows: In the first lot, three control punctures at the top and three inoculations with the attenuated strain below; in the second lot, three inoculations with the virulent strain at the top and three with the attenuated strain below; and in the third lot, three inoculations with the virulent strain at the top and three control punctures below. Six weeks after inoculation, galls developing from the inoculations with the virulent strain had attained diameters ranging from 1 to 2 cm. No swellings developed at the control punctures made below the virulent strain inoculations. From 18 inoculations made with the attenuated strain below control punctures there developed only 4 very small proliferations (1 to 5 mm in diameter), while from an equal number of inoculations made below inoculations with the virulent strain there arose 4 large (10 to 15 mm in diameter) and 5 small (5 mm in diameter) galls.

Similar results were obtained in two other trials involving lots of four and eight plants per treatment, respectively. Results are illustrated in figure 1. In both of these trials the inoculations with the attenuated culture were made 3 days before those with the pathogenic culture in order to reduce the possibility of contamination. These experiments indicate that, when some substance from the tissue inoculated with the virulent strain diffuses down the stem, inoculations with the attenuated strain are stimulated until they equal in size those of the virulent strain. Here, as in other inoculations on tomato with these two cultures, the galls from virulent cultures were without chlorophyll while those from attenuated cultures were green.

BETA-INDOLE-ACETIC ACID

The effect of beta-indole-acetic acid on tissues inoculated with the attenuated strain was tested. Decapitated tomato stems were inoculated at three points near the top with the attenuated strain and the growth substance was applied in lanolin-water paste to the tip of the stub and renewed at weekly intervals during the experiment. Three trials made with lanolin-water paste containing 0.05 mg of beta-indole-acetic acid per gram gave only negative results. The fourth and fifth trials were made with a high concentration of beta-

indole-acetic acid (30 mg per gram of paste). In the fourth trial the axillary buds were removed from the plants. Four weeks after inoculation the stems of plants treated with lanolin-water paste containing beta-indole-acetic acid had grown until their diameters were twice those of the other plants. The results were confused by the appearance of adventitious shoots at the inoculations on the control plants and subsequently of smooth, dark-green galls, possibly conditioned by growth substance originating in the adventitious shoots. Nevertheless, there was apparently a slight stimulation in plants treated with the acid over untreated plants.

A fifth trial with lots of 10 tomato plants each was carried out in the same way except that the axillary buds were not removed and adventitious shoots did not appear. After 10 weeks the galls were removed and weighed. For plants treated with lanolin-water paste containing beta-indole-acetic acid the average weight of gall tissue per plant was 1.04 g. For control plants treated with lanolin-water paste containing no growth substance it was 0.70 g.

These results indicate that, under the conditions of these experiments, beta-indole-acetic acid in high concentration is only slightly effective in stimulating proliferation of tissues inoculated with the attenuated strain, being less effective in this respect than substances diffusing from active galls and from the host plant foliage.

DISCUSSION

It appears from the evidence presented that growth substance is associated with crown gall tissue. Also, it is apparently a limiting factor in the development of galls on tomato by the attenuated strain used.

Several recent writers (*6*, *12*, *22*) have dealt with the parallel between the response of beans to beta-indole-acetic acid and crown gall on various plants. These workers have been very guarded about conclusions. Link, Wilcox, and Link (*22*) report that galls are the result of a causal complex, of which beta-indole-acetic acid possibly is one constituent. The identity of this substance was based on a color reaction with a crude extract and is open to question.

Various nonpathogenic as well as pathogenic organisms produce beta-indole-acetic acid on suitable peptone medium. It has been considered (*22*) that gall production may be initially conditioned by "factors determining infection" rather than by specificity of the chemical mechanism involved. In this connection it is interesting that the attenuated crown gall culture multiplies within tomato stem tissues (*25*) for the common incubation period at approximately the same rate as the virulent cultures. Thus during the incubation period the plant has apparently no bacteriostatic effect on the causal organisms.

In the production of proliferation on beans, beta-indole-acetic acid has been commonly employed at a concentration of 30 mg per gram of lanolin (*6*, *12*, *22*). One-tenth this concentration gave little if any response. As employed by the present writers one application of this paste amounted to one twenty-fifth of a gram and therefore contained 30,000,000 *Avena* units (*3*). During this investigation the greatest amount of growth substance obtained by the *Avena* coleoptile technique from three crown gall inoculations was 83 *Avena* units (table 5).

Yet substances diffusing from three such inoculations produced greater stimulation of tissues inoculated with the attenuated strain than the high concentration of beta-indole-acetic acid employed.

Responses of plants like bean, sunflower, *Coleus*, and *Impatiens* to beta-indole-acetic acid do not parallel their responses to crown gall bacteria (*28*).

Another item for consideration is the number of bacteria involved. In order to obtain enough growth substance to produce significant proliferation with present technique a relatively large quantity of culture must be extracted—a quantity containing a great many times the number of bacteria present in a comparable crown gall.

In view of the evidence now available it seems better to reserve judgment about beta-indole-acetic acid playing a major role in the development of crown gall.

As was pointed out by Leonian (*3, review*) galls may be the result of excessive production of growth substance by the host tissues under the influence of the bacteria rather than the result of growth substance furnished by the pathogen to the host plant. This view finds support in the fact that substances diffusing from the host plant foliage and from active galls are alike in that they stimulate proliferation of tissues inoculated with the attenuated strain much more than do applications of beta-indole-acetic acid. Where they have been identified, growth substances obtained from higher plants have been of the auxin-a or auxin-b type, while those obtained from cultures of bacteria have been of the heteroauxin type, (*3, 38*). It therefore seems probable that the substance coming from the active gall is, like that from the host plant foliage, of the auxin-a or auxin-b type.

SUMMARY

Plants inoculated with a virulent strain of *Phytomonas tumefaciens* exhibit, in addition to gall development, responses that suggest an increase in amount of growth substances present. These responses include (1) increased epinasty of leaf petioles, (2) increased initiation of adventitious roots, (3) stimulated cambial activity, (4) inhibited development of certain buds, and (5) delayed abscission of senescent leaves. An attenuated sister strain was less effective in inducing most of these effects as well as in bringing about gall development.

Adventitious shoots were stimulated on decapitated tomato plants by inoculating the wound with the attenuated culture.

Greater amounts of growth substance were detected by the Went's *Avena* test in inoculated than in comparable uninoculated tissues of tomato seedlings. The amounts detected were equivalent to only a tiny fraction of that commonly used in the beta-indole-acetic acid treatment for production of proliferations on bean.

Preliminary experiments failed to establish a relation between ability of virulent and attenuated cultures to produce growth substance in culture and ability to induce galls in plants.

Growth substance from expanding foliage provided some stimulation to tissue inoculated with the attenuated culture. Such substance from gall tissue induced by a virulent strain stimulated strongly the tissue inoculated by the attenuated strain. Beta-indole-acetic acid was only slightly effective in this respect.

The probable origin and chemical nature of the growth substance or substances involved are discussed. It is concluded that the chief growth substance thus far detected in crown gall is more probably of the auxin-a or auxin-b type than of the heteroauxin type, and that it is more likely a product of the host cells under the influence of the bacteria than a direct bacterial metabolic product.

LITERATURE CITED

(1) Avery, G. S., Jr., Burkholder, P. R., and Creighton, H. B.
1937. production and distribution of growth hormone in shoots of aesculus and malus, and its probable role in stimulating cambial activity. Amer. Jour. Bot. 24: 51–58, illus.

(2) Bauguess, L. C.
1935. plant responses to some indole derivatives. (Abstract) Amer. Jour. Bot. 22: 910–911.

(3) Boysen-Jensen, P.
1936. growth hormones in plants. Authorized English transl. . . . Transl. and rev. by G. S. Avery, Jr., and P. R. Burkholder, H. B. Creighton, and B. A. Scheer. 268 pp., illus. New York and London. [Reviewed by L. H. Leonian in Phytopathology 27: 117–118. 1937.]

(4) Brecht, F.
1936. der einfluss von wuchstoff- und säurepasten auf das wachstum von avena und helianthus keimlingen und seine abhängigkeit vom sauerstoffgehalt der luft. Jahrb. Wiss. Bot. 82: [581]–612, illus.

(5) Brown, N. A.
1929. the tendency of the crown-gall organism to produce roots in conjunction with tumors. Jour. Agr. Research 39: 747–766, illus.

(6) ——— and Gardner, F. E.
1936. galls produced by plant hormones, including a hormone extracted from bacterium tumefaciens. Phytopathology 26: 708–713, illus.

(7) Crocker, W.
1929. a delicate method of detecting illuminating gas in a greenhouse. Florists' Exch. 70: 15, 54, illus. Also in Boyce Thompson Inst. Prof. Paper 1: 81–85.

(8) ——— Zimmerman, P. W., and Hitchcock, A. E.
1932. ethylene-induced epinasty of leaves and the relation of gravity to it. Contrib. Boyce Thompson Inst. Plant Research 4: 177–218, illus.

(9) Hendrickson, A. A., Baldwin, I. L., and Riker, A. J.
1934. studies on certain physiological characters of phytomonas tumefaciens, phytomonas rhizogenes, and bacillus radiobacter. II. Jour. Bact. 28: 597–618, illus.

(10) Hitchcock, A. E.
1935. indole-3-n-propionic acid as a growth hormone and the quantitative measurement of plant response. Contrib. Boyce Thompson Inst. Plant Research 7: 87–95, illus.

(11) ———
1935. tobacco as a test plant for comparing the effectiveness of preparations containing growth substances. Contrib. Boyce Thompson Inst. Plant Research 7: 349–364, illus.

(12) Kraus, E. J., Brown, N. A., and Hamner, K. C.
1936. histological reactions of bean plants to indoleacetic acid. Bot. Gaz. 98: 370–420, illus.

(13) Laibach, F.
1933. wuchsstoffversuche mit lebenden orchideenpollinien. Ber. Deut. Bot. Gesell. 51: 336–340, illus.

(14) ———
1935. über die auslösung von kallus- und wurzelbildung durch beta-indolylessigsäure. Ber. Deut. Bot. Gesell. 53: 359–364, illus.

(15) LAIBACH, F. and FISCHNICH, O.
1935. ÜBER EINE TESTMETHODE ZUR PRÜFUNG DER KALLUSBILDENEN WIRKUNG VON WUCHSSTOFFPASTEN. Ber. Deut. Bot. Gesell. 53: 469–477, illus.

(16) ——— MAI, G., and MÜLLER, A.
1934. ÜBER EIN ZELLTEILUNGSHORMON. Naturwissenschaften 22: 288.

(17) LARUE, C. D.
1935. THE RÔLE OF AUXIN IN THE DEVELOPMENT OF INTUMESCENCES ON POPLAR LEAVES; IN THE PRODUCTION OF CELL OUTGROWTHS IN THE TUNNELS OF LEAF-MINERS; AND IN THE LEAF-FALL IN COLEUS. (Abstract) Amer. Jour. Bot. 22: 908.

(18) LEVINE, M.
1919. STUDIES ON PLANT CANCERS—I. THE MECHANISM OF THE FORMATION OF THE LEAFY CROWN GALL. Bull. Torrey Bot. Club 46: 447–452, illus.

(19) ———
1923. STUDIES ON PLANT CANCERS V. LEAFY CROWN GALLS ON TOBACCO PLANTS RESULTING FROM BACTERIUM TUMEFACIENS INOCULATIONS. Phytopathology 13: [107]–116, illus.

(20) ———
1924. CROWN GALL ON BRYOPHYLLUM CALYCINUM. Bull. Torrey Bot. Club. 51: 449–456, illus.

(21) ——— and CHARGAFF, E.
1937. THE RESPONSE OF PLANTS TO CHEMICAL FRACTIONS OF BACTERIUM TUMEFACIENS. Amer. Jour. Bot. 24: 461–472, illus.

(22) LINK, G. K. K., WILCOX, H. W., and LINK, A. D.
1937. RESPONSES OF BEAN AND TOMATO TO PHYTOMONAS TUMEFACIENS, P. TUMEFACIENS EXTRACTS, β-INDOLEACETIC ACID, AND WOUNDING. Bot. Gaz. 98: 861–867, illus.

(23) LOCKE, S. B, RIKER, A. J., and DUGGAR, B. M.
1937. A GROWTH HORMONE IN THE DEVELOPMENT OF CROWN GALL. (Abstract) Phytopathology 27: 134.

(24) LYNEIS, M. M., RIKER, A. J., and LOCKE, S. B.
1936. COMPARATIVE PHYSIOLOGY OF PATHOGENIC AND NON-PATHOGENIC CROWN-GALL BACTERIA. (Abstract) Phytopathology 26:100.

(25) NĚMEC, B.
1930. BAKTERIELLE WUCHSSTOFFE. Ber. Deut. Bot. Gesell. 48: 72–74.

(26) RIKER, A. J.
1923. SOME MORPHOLOGICAL RESPONSES OF THE HOST TISSUE TO THE CROWNGALL ORGANISM. Jour. Agr. Research 26: 425–435, illus.

(27) ——— and BERGE, T. O.
1935. ATYPICAL AND PATHOLOGICAL MULTIPLICATION OF CELLS APPROACHED THROUGH STUDIES ON CROWN GALL. Amer. Jour. Cancer 25: 310–357, illus.

(28) ——— and NAGY, R.
1938. CELL STIMULATION BY CHEMICALS IN RELATION TO CROWN GALL. (Abstract) Phytopathology 28: 18–19.

(29) SMITH, E. F.
1916. STUDIES ON THE CROWNGALL OF PLANTS. ITS RELATION TO HUMAN CANCER. Jour. Cancer Research 1: 231–258, illus.

(30) ———
1917. EMBRYOMAS IN PLANTS. (PRODUCED BY BACTERIAL INOCULATIONS). Bull. Johns Hopkins Hosp. 28 (319): [277]–294, illus.

(31) ———
1921. EFFECT OF CROWNGALL INOCULATIONS ON BRYOPHYLLUM. Jour. Agr. Research 21: 593–598, illus.

(32) ———
1922. APPOSITIONAL GROWTH IN CROWN-GALL TUMORS AND IN CANCERS. Jour. Cancer Research 7: 1–49, illus.

(33) ——— BROWN, N. A., and TOWNSEND, C. O.
1911. CROWN-GALL OF PLANTS: ITS CAUSE AND REMEDY. U. S. Bur. Plant Indus. Bull. 213, 215 pp., illus.

(34) SNOW, R.
1931. EXPERIMENTS ON GROWTH AND INHIBITION. I.—THE INCREASE OF INHIBITION WITH DISTANCE. Roy. Soc. [London], Proc. (B) 108: 209–223, illus.

(35) SNOW, R.
1931. EXPERIMENTS ON GROWTH AND INHIBITION. PART II.—NEW PHENOMENA OF INHIBITION. Roy. Soc. [London], Proc. (B) 108: 305–316.
(36) ———
1935. ACTIVATION OF CAMBIAL GROWTH BY PURE HORMONES. New Phytol. 34: 347–360, illus.
(37) ——— and LE FANU, B.
1935. ACTIVATION OF CAMBIAL GROWTH. Nature [London] 135: 149.
(38) THIMANN, K. V.
1935. ON THE PLANT GROWTH HORMONE PRODUCED BY RHIZOPUS SUINUS. Jour. Biol. Chem. 109: 279–291, illus.
(39) ———
1936. AUXINS AND THE INHIBITION OF PLANT GROWTH. (Abstract) Amer. Jour. Bot. 23 (Sup.): 689–690.
(40) ——— and KOEPFLI, J. B.
1935. IDENTITY OF GROWTH-PROMOTING AND ROOT-FORMING SUBSTANCES OF PLANTS. Nature [London] 135: 101–102.
(41) ——— and SKOOG, F.
1933. STUDIES ON THE GROWTH HORMONE OF PLANTS. III. THE INHIBITING ACTION OF THE GROWTH SUBSTANCE ON BUD DEVELOPMENT. Natl. Acad. Sci. Proc. 19: 714–716.
(42) ——— and SKOOG, F.
1934. ON THE INHIBITION OF BUD DEVELOPMENT AND OTHER FUNCTIONS OF GROWTH SUBSTANCE IN VICIA FABA. Roy. Soc. [London], Proc. (B) 114: 317–339, illus.
(43) ——— and WENT, F. W.
1934. ON THE CHEMICAL NATURE OF THE ROOTFORMING HORMONE. R. Acad. Sci. Amsterdam, Proc., Sec. Sci. 37: [456]–459.
(43a) WENT, F. W.
1928. WUCHSSTOFF UND WACHSTUM. Rec. Trav. Bot. Néerl. 25: 1–116, illus.
(44) ZIMMERMAN, P. W., CROCKER, W., and HITCHCOCK, A. E.
1933. INITIATION AND STIMULATION OF ROOTS FROM EXPOSURE OF PLANTS TO CARBON MONOXIDE GAS. Contrib. Boyce Thompson Inst. Plant Research 5: 1–17, illus.
(45) ——— CROCKER, W., and HITCHCOCK, A. E.
1933. THE EFFECT OF CARBON MONOXIDE ON PLANTS. Contrib. Boyce Thompson Inst. Plant Research 5: 195–211, illus.
(46) ——— and HITCHCOCK, A. E.
1933. INITIATION AND STIMULATION OF ADVENTITIOUS ROOTS CAUSED BY UNSATURATED HYDROCARBON GASES. Contrib. Boyce Thompson Inst. Plant Research 5: 351–369, illus.
(47) ——— and WILCOXON, F.
1935. SEVERAL CHEMICAL SUBSTANCES WHICH CAUSE INITIATION OF ROOTS AND OTHER RESPONSES IN PLANTS. Contrib. Boyce Thompson Inst. Plant Research 7: 209–229, illus.

A PHOTOELECTRIC SORTER FOR LENGTH MEASUREMENTS OF FIBERS OF SEED COTTON[1]

By BURT JOHNSON

Assistant agronomist, Arkansas Agricultural Experiment Station

INTRODUCTION

Both the cotton breeder and the textile engineer are concerned with the important factor of the length of cotton fibers, especially the average length of the fibers and the dispersion of lengths from the average. The original degree of uniformity of the fibers as found on the cotton seed may be disturbed by the effects of ginning, baling, compressing, and the several spinning operations. Although the breeder must not lose sight of the effects of the several industrial processes on fiber-length uniformity, he is more directly concerned with uniformity of the fibers as found on the cotton seed.

The purpose of this paper is to describe an apparatus for sorting cotton fibers as to length by the use of a photoelectric cell.[2] At present the method has not been adapted to ginned lint, or to multiple-seed sortings, but this fundamental or basic design of the apparatus can be adapted, if necessary, to fit other needs and problems. For example, modifications of this fundamental design to handle several seeds at a time might be made. As now constructed, the machine is especially applicable to the work of the cotton breeder and agronomist. It offers a rapid and practical means of sorting fibers as to length within satisfactory limits of accuracy.

METHODS OF OTHER WORKERS

Regardless of the contributing factors affecting the degree of uniformity of lint, there remains the very practical consideration of methods of measuring fiber lengths. Cotton breeders are especially anxious to use rapid means of sorting cotton fibers as to length, and mechanical sorters have been used to good advantage in breeding work. Several ingenious means of meeting this need along with discussions and criticisms of their utility may be found in the literature (*1*, *4*, *6*, *7*, *8*, *11*, *13*).[3] The purpose here is not to describe in detail each of these methods, but rather to discuss briefly certain mechanical or sampling problems as recorded by the authors of the methods or by critics of the methods.

The difficulty with most of the methods in present use, for practical purposes, is their slowness of operation. In some cases a considerable degree of skill must be developed before reliable results can be obtained. With all methods there is the difficulty of securing suitable

[1] Received for publication January 27, 1938; issued July 1, 1938. Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station. Research paper No. 498, Journal Series, University of Arkansas.

[2] The application of this particular technique to the sorting of cotton fibers originated with Dr. O. A. Pope while with the Arkansas Agricultural Experiment Station. The basic design of the machine which employed has been retained. The writer applied methods of maintaining steady light sources and used the apparatus extensively in breeding, genetic, and agronomic experimental work.

[3] Italic numbers in parentheses refer to Literature Cited, p. 56.

samples. Difficulty in sampling is not necessarily due to defects in the methods of sorting, but is inherent in the nature of cotton itself. Problems of sampling are met whether the sorting method uses the composite sample offered by ginned cotton, or samples taken from seed cotton. These sampling difficulties in the cotton itself may be partly overcome by more rapid sorting of larger samples. However, it has been pointed out that most of the variability found in lint of Pima cotton is contributed by the seed itself and larger samples of seed cotton would closely approximate the variability of lint lengths found on a single seed (*10*). This observation is probably applicable in somewhat less degree to other cottons.

A present method for ginned cotton as embodied in the Suter-Webb (*13*) and similar sorters has the advantage of a composite sample, but the process is slow. Any other method, such as Ball's sledge sorter, for ginned cotton also has the advantages of a composite sample if the sample is properly prepared. Ahmad and Nanjundayya (*1*) have recently described a sorter which determines the average length of ginned cotton perhaps more rapidly than other manual methods. However, on the face of it, it seems that this method would give only one statistic—average length—and would ignore the percentage of waste fibers, the model length, and dispersion from the average. By this method these authors also claim to obtain a measure of fineness.

Several methods for sorting lint still attached to the cotton seed have been devised in this country. Machines have been made to handle one (*6*) or more (*8*) seeds at a time. Such sorters have been used advantageously by breeders and agronomists (*9*), (*12*). The aim of these devices is to increase the speed of sorting and to take advantage of the approximate alignment of the basal ends of the fibers on the seed coat. McNamara and Stutts (*6*) have discussed the accuracy of this alignment and also the degree of alignment obtained at the distal ends of the fibers where they are grasped by the forceps.

All the methods thus far mentioned may under certain conditions give additional short fibers due to breakage during the sorting process itself. However, in the hands of a skilled operator, such possible breakage is probably a negligible factor.

Hertel and Zervigon (*4*) have employed a method of sorting fibers as to length by the use of a device employing photoelectric cells. This apparatus was originally designed to sort fibers on a single cotton seed. The advantage of the approximate alignment of the fibers on the seed coat was largely counteracted by the number of seeds required for a good sample. Nevertheless, this method for a single seed is comparatively rapid. This device is now used for sorting lint as found in rovings, and a theoretical consideration (*3*) has been given to the accuracy that can be obtained with ginned cotton partially parallelized in the manufacture of the roving.

Hertel's apparatus employs two photoelectric cells balanced against each other in relation to a single source of light and connected in parallel with a galvanometer. A cam, shaped according to considerations of theory and experimentation, is moved between the light and one of the photoelectric cells at a rate proportionate to the number of fibers lying between the light and the other photoelectric cell. The drawing of the cotton lint between the light and the photoelectric cell moves a pen, while the movement of the cam moves a card at right

angles to the movement of the pen. The results of the fiber length distribution are recorded as a curve on the card. Hertel has discussed the statistics that may be derived from this curve (*3*).

DESCRIPTION OF PHOTOELECTRIC LINT-SORTING APPARATUS FOR SEED COTTON

An apparatus somewhat different in principle from Hertel's has been used in the cotton fiber laboratory of the Arkansas Agricultural Experiment Station. The apparatus consists essentially of a boxlike cabinet having a curved slit in the lid. Suitable devices are provided for holding a combed cotton seed and for drawing the parallelized fibers across the slit. Inside the box and directly under the slit is mounted a photoelectric cell. This very simple arrangement is sup-

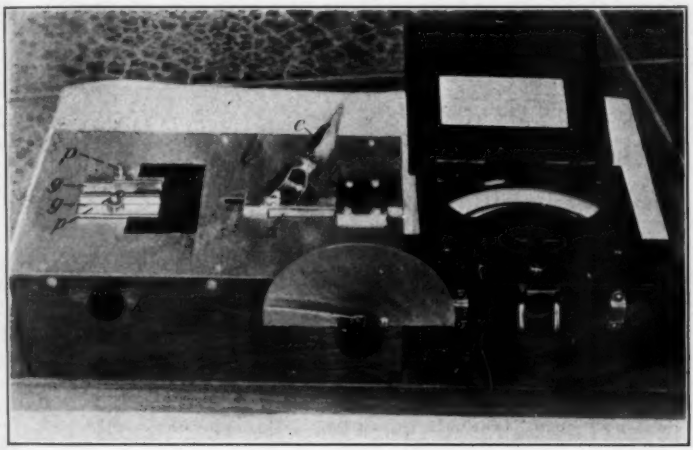

FIGURE 1.—View of assembled photoelectric cotton-sorting apparatus: *l*, Lid; *c*, clamp; *b*, bar; *h*, handle of clamp-moving device; *a*, scale; *k*, handle of guide-moving device; *p*, pillar; *g*, guide.

plemented by several accessories, as follows: To the photoelectric cell is connected a microammeter of 300 microamperes range. Light is directed downward on that part of the lint lying over the slit. In the light housing is a 6-volt, 18-ampere, ribbon-filament bulb. This shape of filament more adequately covers the long narrow slit than would other kinds of filaments. Through openings in the light housing, the light beam is passed through a series of lenses and mirrors (this type bulb must stand upright, base down) to place an image of the ribbon filament on the cotton over the slit. The current to the light bulb is passed successively through a voltage regulator for producing a steady current, a 6-volt transformer, and a common tumbler switch. A steady voltage is essential, but other methods for the same purpose might be used. The source of light is so arranged that two photoelectric sorters can be operated at the same time from the one light.

Figures 1 and 2 show in detail the construction of the sorting apparatus. The slit (*s*) in the lid (*l*) is curved slightly as a partial compensation for the curvature of the seed. The inside and the outside

arcs of the slit are made on radii of three fourths and thirteen sixteenths of an inch, respectively, and are concentric. The distance on a straight line through this slit varies from place to place. Therefore, a slit made so that the edges are eccentric to each other might produce a more accurate reading. Guides (*g*) can be opened or closed over the slit by turning a knob (*k*). The guides for all the work reported in this paper were seventeen thirty-seconds of an inch apart. The pillars (*p*), to which the guides are fastened, are moved backward and forward by left- and right-hand threads on the shaft (*m*). The purpose of the guides is to confine all the lint over the slit. By adjusting the space between them, the width of opening for any par-

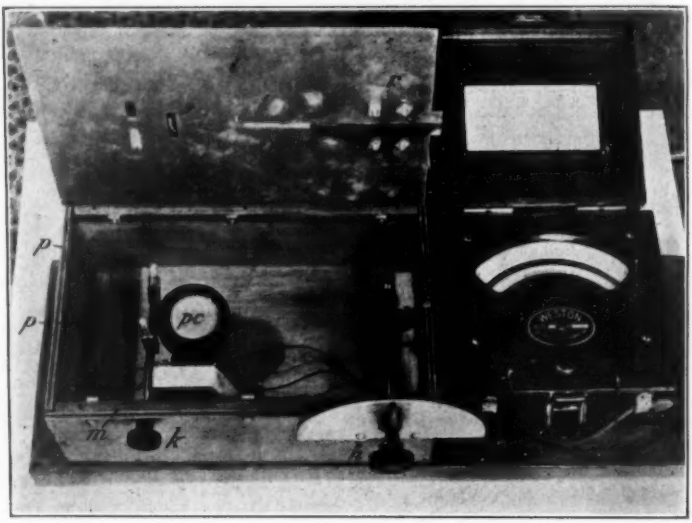

FIGURE 2.—View of photoelectric cotton sorting apparatus with lid of cabinet laid back to show interior of cabinet: *s*, Slit; *r*, rack; *t*, gear; *pc*, photoelectric cell; *m*, shaft with right- and left-hand threads. Other symbols as in figure 1. The microammeter at right is connected directly to the photoelectric cell.

ticular requirements of light or sample can be met. The photoelectric cell is indicated by *pc*.

A previously combed cotton seed is placed in the clamp (*c*). The gear (*t*), moved by turning (*h*), engages the rack (*r*). This rack is attached to the bar (*b*), to which the clamp (*c*) is fastened. On the bar is a mark which is alined with the zero of the scale (*a*), having 1/16-inch divisions.

In operation, the fibers, after being combed, are further straightened as much as possible between the fingers, and the combed seed is then placed in the clamp. The clamp is swung downward and the fibers are placed between the guides. By manipulation with the fingers, the fibers are straightened out as much as possible between the guides, and the mark on the bar brought up to the 1/16-inch mark on the scale. A reading is made from the microammeter. The bar, clamp, and seed are moved back one sixteenth-inch more, and another reading from

the microammeter is recorded. This is repeated until all the fibers have been pulled past the slit, a reading being taken each one-sixteenth inch. The final reading is a blank with no fibers over the slit.

The seed is then removed from the clamp, reversed, the fibers on the other half of it straightened, and the combed seed returned to the clamp ready to have the second half of the lint sorted. In this way all the fibers are sorted, eliminating the very serious error that may occur when only part of the fibers is considered. The great irregularity in lint length that may occur on a single seed has been noted by other investigators, among whom may be mentioned Cook (*2*), Hertel and Zervigon (*4*), Pope (*7*), and Richmond and Fulton (*10*). Class lengths other than one-sixteenth of an inch may well be used when the degree of separation need not be too minute. For most practical or routine purposes the ⅛-inch class length is perhaps to be preferred. In practice it has been found that when using

Length in 1/16 inch (L)	Readings in μa amps		(2) plus (3)	New and adjusted readings in μa amps	Absorption in μa amps	Percent absorption	Fractional number of fibers in percent (F)	Cumulative percentage	LF
	First half	Second half							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	70	34	104	0	372	100.00	0.00		
2	73	34	107	3	369	99.19	.81		1.62
3	75	35	110	6	366	98.39	.80		2.40
4	75	35	110	6	363	97.58	.81	2.42	3.24
5	53	48	101	21	351	94.35	3.23		16.15
6	108	68	176	64	308	82.80	11.29		67.74
7	157	124	281	177	195	52.42	30.64		214.48
8	237	194	431	317	55	14.78	37.64		301.12
9	238	238	476	372	0	0.00	14.78	100.00	133.02
10									
Percent ½ inch and less					::Percent longer than ½ inch				
Modal length									
Percent number of fibers in three 1/8-inch primary modal groups									
Σ of (10) 739.77			Mean 7.40/8 inch = ± /8 inch				Coefficient of variability		

FIGURE 3.—Form of work sheet and sample calculation for the length sorting of fibers from one cotton seed.

the ⅛-inch class length, an operator can sort an average of 12 seeds an hour. This average is based on the use of long-, medium-, and short-staple cottons just as they come to hand from a randomized variety test. The seeds are previously combed, and this operation would reduce the number of sortings per hour if the operator also had to comb his cotton.

CALCULATIONS

The present method of calculating the data from the work sheets is as follows: The readings at the corresponding length groups of both halves (columns 2 and 3, fig. 3) of the combed seed are added (column 4). This includes the final or blank reading. Next the total reading from the shortest length group measured (one-eighth inch) is then subtracted in turn from each of the other readings, giving readings based on the relative number of fibers found in that particular sample, as shown in column 5. As a consequence, the first reading is always zero. Then, these new readings are each in turn subtracted from the combined blank (or final) reading, which gives the amount of light absorbed by the fibers (column 6). The

percentage absorption is found by dividing the blank (or final) reading into each of the absorptions at the several length intervals in turn. These percentages are recorded in column 7. As a result, the first reading will be 100 percent absorption and the final reading no absorption.

The determination of the relative number of fibers in a length group is accomplished by subtracting the percentage absorption for that length group from the next shortest length group, or simply by subtracting the percentage of absorption from the one above it (column 8). In the data given in this paper, the bottom point of each length group has been used as the point of measurement. The cumulation of the fractional length percentages (column 9) not only serves to show the percentages of fibers in a set of length groups (e. g. the percentage one-half inch and less in length), but it also acts as a partial check on the accuracy of the subtractions in the "percentage of absorption" column. Or an ogive curve could be constructed directly from the cumulations if each were entered in column 9 (such data are not shown in fig. 3).

The proportionate total length of fibers in any length group is found by multiplying the value of each length group (column 1) by the percentage fractional number of fibers for the corresponding length group (column 8). The result is placed in column 10. These values are then added and the sum divided by 100 to give the mean length of fibers in the entire sample. In the illustration (fig. 3) the class length used was one-eighth inch.

From data of this type, the modal group is readily selected, percentages of fibers in any one length group or in combinations of length groups are readily obtained, mean length based on relative number of fibers is determined, and measures of dispersion may be calculated. Figure 3 shows some of these data with suggestions as to other possible statistics.

In practice, a table is used to convert the readings in column 5 to "absorption in microamperes" and "percent absorption" (columns 6 and 7, respectively). As a further saving of time, the data in column 6 usually are not copied. The data in this column, after having been used in the calculation of "percent absorption" in the conversion table, do not enter further into the computations on the work sheet.

EXPERIMENTS WITH THE PHOTOELECTRIC SORTER

A large number of samples of seed cotton from various kinds of fertilizer, breeding, and genetics tests have been sorted with the photoelectric sorter. These data are not presented here in toto, but only such parts as show the advantages, disadvantages, and degree of accuracy of the method. The photoelectric sorting method gives satisfactorily comparable results in a series of determinations. Such measurements would be of comparable value among themselves, but might be difficult to correlate in terms of other methods. A method may also be compared directly to some method whose accuracy is generally accepted as giving a true concept of the reliability of the method under test. Both kinds of data are given below.

It is necessary to know whether or not repetition of sortings on a given sample by the photoelectric sorting method will give duplicate results. Data from an experiment to establish whether or not results

secured by operator A using instrument A could be repeated by operator B with instrument B are found in tables 1 and 2. No attempt had been made to calibrate these sorters in terms of one or the other. However, the effect of the intensity of light on results will later be pointed out. In this experiment 10 cotton seeds were selected representing various lengths of staple, each seed being an individual sample. Operator A made three photoelectric fiber sortings of each seed on instrument A. Then operator B, using instrument B, repeated this process three times with the same samples. By using Student's method (as discussed by Love and Brunson (*5*)), the odds that a real difference in results in this experiment were found to be 38:1. The raw data are given in table 1. The average lengths found for each sorting were determined separately and recorded in the columns "mean lint lengths of individual sortings" of table 1. The extreme differences of the mean lengths and the mean of three lint sortings of each seed are likewise recorded.

TABLE 1.—*Comparison in detail of average length of cotton lint from 10 separate seeds fractioned by 2 operators on 2 photoelectric sorters*

[Each operator made 3 sortings of lint on each seed. A sample consists of 1 seed]

Sample No.	Instrument A, operator A			Instrument B, operator B		
	Mean lint lengths of individual sortings	Extreme difference of mean lengths	Mean of 3 lint sortings of each seed	Mean lint lengths of individual sortings	Extreme difference of mean lengths	Mean of 3 lint sortings of each seed
	1/16 *inch*	1/16 *inch*	1/16 *inch*	1/16 *inch*	1/16 *inch*	1/16 *inch*
1	12.96 12.95 12.96	0.01 (0.000625 inch)	12.96	13.95 14.21 14.16	0.26 (0.01625 inch)	[1] 14.11
2	13.76 13.79 13.80	.04 (.0025 inch)	13.78	15.06 14.57 14.99	.49 (.030625 inch)	[2] 14.87
3	16.09 16.24 16.20	.15 (.009375 inch)	16.18	16.67 16.28 16.43	.39 (.024375 inch)	16.46
4	15.42 15.54 15.39	.15 (.009375 inch)	15.45	15.19 15.18 15.22	.04 (.0025 inch)	15.20
5	11.88 11.94 11.91	.06 (.00375 inch)	11.91	11.72 11.74 11.87	.15 (.009375 inch)	11.78
6	12.21 12.21 12.21	.00	12.21	11.98 12.30 12.31	.33 (.020625 inch)	12.20
7	19.12 19.22 19.40	.28 (.0175 inch)	19.25	19.53 19.58 19.62	.09 (.005625 inch)	19.58
8	18.12 17.80 18.17	.68 (.0425 inch)	[3] 18.03	18.96 19.04 19.21	.25 (.015625 inch)	19.07
9	19.22 19.07 19.17	.15 (.009375 inch)	19.15	19.43 19.82 19.62	.39 (.024375 inch)	19.62
10	18.44 18.45 18.45	.01 (.000625 inch)	18.45	18.72 18.93 19.04	.32 (.02 inch)	18.90

[1] Operator B inexperienced with this instrument. Sample resorted by A, who found an average length of 13.42 sixteenths of an inch.
[2] Operator B inexperienced with this instrument. Sample resorted by A, who found an average length of 13.90 sixteenths of an inch.
[3] Careless sorting by A. Resorted by A, who found an average length of 18.23 sixteenths of an inch.

In table 1, attention is directed to the wide differences between the results on the two sorters in the case of samples 1, 2, and 8. The fact that the other differences are so slight would indicate as regards

these particular samples that one or both of the operators were in error. For samples 1 and 2, operator A was inexperienced in the use of instrument B, and a more nearly correct sorting by operator B was made. Apparently, with sample 8, both operators were in error, especially B. But the error is so obvious that a redetermination was indicated. This was done, with the results shown. It seems that an acceptable degree of agreement between two operators using two instruments not especially calibrated in terms of a standard can be expected. Further, it seems that a single operator can be expected to produce consistent results, his extreme difference in the determination of mean length of lint on a seed seldom being much over 0.02 inch.

TABLE 2.—*Comparison in detail of modal lengths of cotton lint from 10 separate seeds fractioned by 2 operators on 2 photoelectric sorters*

[Each operator made 3 sortings of lint on each seed. A sample consists of 1 seed]

Sample No.	Instrument A, operator A		Instrument B, operator B		Extreme difference of all modes by both sorters	Sample No.	Instrument A, operator A		Instrument B, operator B		Extreme difference of all modes by both sorters
	Modes of 3 trials	Extreme difference of modes	Modes of 3 trials	Extreme difference of modes			Modes of 3 trials	Extreme difference of modes	Modes of 3 trials	Extreme difference of modes	
	1/16 inch	1/16 inch	1/16 inch	1/16 inch	1/16 inch		1/16 inch	1/16 inch	1/16 inch	1/16 inch	1/16 inch
1	14 14 14	0	14 14 15	1	1	6	12 12 12	0	12 13 13	1	1
2	13 14 14	1	14 14 14	0	1	7	20 20 19	1	20 20 20	0	1
3	17 17 17	0	17 17 17	0	0	8	19 19 19	0	19 19 18	1	1
4	16 17 17	1	16 16 15	1	2	9	19 19 20	1	19 19 19	1	
5	12 12 12	0	12 12 13	1	1	10	19 19 19	0	19 19 19	0	0

Equally consistent results from the same experiment are shown in the determination of the modal lengths of the lint from the 10 seeds (table 2). These determinations were made at 1/16-inch intervals. In routine work 1/8-inch intervals are generally used. Such being the case, the modal lengths in this experiment probably would have agreed even more closely had the 1/8-inch length grouping been used with its consequent sacrifice of the accuracy of the finer readings.

Ninety other seeds were sorted in a manner similar to the one described for the 10 seeds referred to above, except that each operator made only one sorting to a seed instead of three. The results are collected in table 3, where the differences between the two operators and two instruments, as shown by comparisons in mean length and modal length of lint found on a given seed, are combined in group values of tenths of 1/16 inch, and the number of averages showing the corresponding range of differences are placed in the designated columns. In comparing the differences in modal lengths a class value of 1/16 inch (the interval at which measurements were made) is used. Again, it will be seen that the agreement continues to be close, most of the averages showing a difference of less than 1/32 inch, and the

modal lengths usually being equal or separated by not more than one length class.

Mention has been made of the importance of the intensity of light. Reference to table 1 will show that 7 times out of 10 a higher reading was secured on instrument B than on A. This might have been due to an error on the part of the operator rather than to an error in the method. The photoelectric cell in B has about one-half the amperage output of the cell in instrument A. Therefore, the light intensity on the cell in B, other things being equal, will have to be considerably greater than that on the cell in A, if the amperage output is to be equal.

TABLE 3.—*Grouped comparisons of average and modal lengths of lint on 90 cotton seeds sorted on 2 photoelectric fiber sorters by 2 operators*

[Class differences for mean lengths are in terms of tenths of a sixteenth of an inch; class differences for modal lengths are in terms of one-sixteenth of an inch]

Difference in mean lengths (1/16 inch)	Frequency	Difference in modal lengths (1/16 inch)	Frequency
0.00 to 0.10	16	0.00	50
0.11 to 0.20	18	1.00	37
0.21 to 0.30	12	2.00	3
0.31 to 0.40	17		
0.41 to 0.50	8		
0.51 to 0.60	9		
0.61 to 0.70	3		
0.71 to 0.80	2		
0.81 to 0.90	2		
0.91 and above	3		
Total	90	Total	90

In a test in which the current outputs from both instruments were adjusted to be approximately equal, the following averages on the same sample were made by one operator:

Instrument A.—7.16; 7.12; 7.12; 7.02; 7.07. Extreme difference, 0.14-eighths of an inch.
Instrument B.—7.49; 7.46; 7.50. Extreme difference, 0.04-eighths of an inch.

For instrument B, the modal length was eight-eighths of an inch and that for A, seven-eighths of an inch.

As seen from the data, there are consistently higher readings from the sorter with the weaker cell. This may be due to the relationship between the quality of light of high intensity to absorption by lint as it affects a photoelectric cell. However, the writer is of the opinion that most of the discrepancy in this case is due to the comparatively small area of the light image on the fibers. In order to obtain a high amperage output from instrument B, it was necessary to have an intense beam of light in which the outer fringes of the light image are definitely less intense than toward the center. The shorter fibers often found toward the ends of the seed are not as well scanned in the much weaker light of this outer fringe. If these short fibers were incorporated more accurately in the sortings done on instrument B, very likely the readings would be more nearly comparable to those on A. Instrument A can show a high reading on the microammeter and still have a band of light of even intensity extending far beyond the mass of fibers being scanned. The later practice in this laboratory has been to sacrifice, in the case of instrument B, the accuracy of reading

expected with a high current output for the greater accuracy of a more diffuse light more equally scanning all fibers. In spite of this, exact comparability has not yet been achieved. It appears that apparatus of this sort should be equipped with the more sensitive type of cells and all instruments formally calibrated against some standard instrument.

When data from the same 90 seeds referred to in table 3 were used, the total of the mean lengths as given by instrument A was 1.91 percent shorter than the total of the mean lengths given by instrument B on the same samples. This is of the same general magnitude as the differences shown in table 1, and a similar figure might be used as a correction factor in order to get these sorters calibrated in terms of one of them.

Ten samples of seed cotton, some samples consisting of one seed only, and the others of two seeds, were sorted by the photoelectric method. The fibers from each seed were then carefully ginned by hand, and in the case of the samples with two seeds, the fibers from both seeds were combined into a composite sample. An aliquot of each sample of ginned lint was withdrawn and the individual fibers measured to the nearest one-sixteenth of an inch. The results are given in table 4. In all cases the measurements of fibers less than five-sixteenths of an inch long were disregarded, because, except in the shortest staple cottons, the photoelectric method does not accurately measure the short fibers. This point will be discussed below.

In this experiment the agreement between the photoelectric method and measurements of single fibers is fairly close in the case of the short and medium staples, considering the limitations of such an experiment in the factors of the size of aliquot used and the difficulty of obtaining a representative aliquot. The sources of error in the photoelectric method seem to be largely inaccurate measurement of the few shortest and longest fibers.

TABLE 4.—*Comparison of mean and modal lengths as found by photoelectric sorting with measurements of individual fibers*

Sample No.	Seed No.	Single fibers measured	Mean length by—		Modal length by—	
			Photoelectric sorting	Single-fiber measurements	Photoelectric sorting	Single-fiber measurements
		Number	*1/16 inch*	*1/16 inch*	*1/16 inch*	*1/16 inch*
1	1	937	15.09	15.24	16	15
2	1	1,141	15.55	15.84	16	17
	2		16.53		17	
3	1	1,223	19.22	20.72	20	23
	2		18.17		19	
4	1	554	18.56	18.22	19	20
5	1	438	19.93	18.20	21	22
6	1	789	14.44	14.04	15	15
7	1	590	11.00	11.34	11	11
8	1	620	13.40	13.42	13	14
9	1	1,252	10.58	10.79	11	11
	2		9.51		10	
10	1	475	15.88	14.81	16	15

In table 5 are data on the number of seeds required for accuracy in photoelectric sorting. As will be noted, no attempt was made to remove the effect of locations by variance. Thus this test was very

rigorous and the number of seed required, as shown, is probably more than sufficient for most purposes for the accuracy indicated. Each of the 5 varieties was grown at 12 locations, scattered to give a wide range of the soil and climatic types found in the cotton-growing districts of Arkansas. The 6 locations (superior locations), where the lint was longest as shown by stapling, furnished 92 seeds sorted for each variety. The other 6 locations (inferior locations) were in the dry and hill sections of the State and furnished 96 seeds sorted for each variety. Nevertheless, the variability from location to location is marked even within the groups of "inferior locations" or "superior locations." To add to the rigor of the test, both instruments and two operators sorted these samples, and the cotton from one of the locations was sorted by three different operators.

TABLE 5.—*Size of sample required for specified accuracies in determination of mean length of fibers by means of photoelectric sorting*

[See text for source of populations]

Variety	Seeds tested	σ	Number of seeds (n) for an accuracy of—	
			$\frac{2\sigma}{\sqrt{n-1}}$ = 1/32 inch	$\frac{2\sigma}{\sqrt{n-1}}$ = 1/16 inch
	Number	*1/64 inch*	*Number*	*Number*
INFERIOR LOCATIONS				
Coker-Wilds 7	96	0.583	23	7
Missdel 3-9818	96	.688	32	9
D. & P. L. 11A	96	.506	18	6
Rowden 2088	96	.550	21	6
Half and Half	96	.462	15	5
SUPERIOR LOCATIONS				
Coker-Wilds 7	92	0.637	25	8
Missdel 3-9818	92	.696	32	9
D. & P. L. 11A	92	.682	31	9
Rowden 2088	92	.545	20	6
Half and Half	92	.543	20	6

In sorting 216 seeds of Rowden 5056, taken from a fertilizer test at one location, a standard deviation of 0.52 eighth of an inch was found for the entire test. This sorting was done by three comparatively inexperienced operators. The sizes of samples required were:

Where $n=40$ seeds, $\frac{3\sigma_z}{\sqrt{n-1}}=1/32$ inch

Where $n=11$ seeds, $\frac{3\sigma_z}{\sqrt{n-1}}=1/16$ inch

Where $n=19$ seeds, $\frac{2\sigma_z}{\sqrt{n-1}}=1/32$ inch

Where $n=6$ seeds, $\frac{2\sigma_z}{\sqrt{n-1}}=1/16$ inch

Variance was applied to data from 16 varieties in the 12 locations mentioned above, as regards the factors of mean length and modal length. The plantings in these tests were so arranged that this method of statistical analysis was applicable. Eleven of these tests were 16 × 8 semi-Latin squares and one was a 24 × 6 semi-Latin square. They were all randomized and doubly restricted. A summary of the standard errors of the individual is given in table 6. These standard errors are somewhat lower than those shown in table 5, because the variance removes the variation due to varieties and to soil variations in both directions across the field. The regularity of these standard errors and the similarity of the differences required for significance between varieties all tend to show the uniformity of work done by the photoelectric method.

TABLE 6.—*The variance of 16 varieties of cotton at 12 locations in Arkansas, showing a comparison between locations as regards the standard error of the individual, and the significant differences between varieties in the factors of mean length and modal length of lint*

Location	Standard error of individual		Difference required for significance between varieties			
			Mean		Mode	
	Mean	Mode	19:1	99:1	19:1	99:1
	1/16 inch	*1/16 inch*	*1/16 inch*	*1/16 inch*	*1/16 inch*	*1/16 inch*
Warren	0.5319	0.5083	0.52	0.69	0.50	0.66
England	.4022	.4515	.39	.52	.44	.58
Marianna	.3871	.3876	.38	.50	.38	.50
Hope	.3900	.4261	.44	.58	.48	.63
Magnolia	.3845	.4575	.38	.50	.45	.59
Lake Village	.4419	.4538	.43	.57	.44	.59
Joiner	.3822	.4061	.37	.49	.40	.52
Blytheville	.3743	.4140	.37	.48	.41	.53
Brookland	.3809	.4281	.37	.49	.42	.55
Myron	.3859	.4425	.38	.50	.43	.57
Damascus	.4787	.5341	.47	.62	.52	.69
Newport	.4011	.3921	.39	.52	.38	.51

The results from the tests at Warren and Damascus (table 6) require further explanation. The standard errors in both cases deviate noticeably from the general magnitude of the standard errors at the other locations. The test at Warren was sorted by three relatively inexperienced operators. The test cotton at Damascus was grown under conditions of such extreme drought that the lint was very immature, brash, difficult to manipulate, and perhaps quite irregular. The photoelectric method seems to be sensitive enough to detect these irregularities induced by inexperienced operators or conditions under which the crop is grown.

From all the evidence it seems that sorting a sample of 10 seeds from each row in each location by the photoelectric method would be amply sufficient to give an accurate result. If this number had been used in the work reported in table 5, a total of 480 seeds would have been sorted for each variety for the inferior locations and 460 for the superior locations. The degree of precision provided by a 10-seed sample is probably great enough for most studies on utility and genetics. Hertel and Zervigon (*4*) say that at least six seeds are required in the sample for their photoelectric sorter.

The error arising from the inability of the photoelectric sorter adequately to scan the shortest fibers is one of the most difficult to explain and to rectify. The seriousness of this error is shown in table 7. These results were secured by making a photoelectric sorting of one-half of the fibers of each of six seeds. These fibers were then sorted on the McNamara-Stutts sorter. All the fibers lying between any two combs of the sorter were grouped into a class interval of one-eighth inch. The readings for the McNamara-Stutts sorting as recorded in the table are conservative. In column *P* is given the length class which showed by photoelectric sorting a higher reading on the ammeter than the first reading for the ⅛-inch length class (i. e., it is the first length class showing fewer fibers than the shortest length class).

TABLE 7.—*Numbers of fibers not adequately recorded by the photoelectric fiber sorter*

[Column *P* records the length class where the first positive reading with the photoelectric sorter was made

Seed No.	Photoelectric sorter			McNamara-Stutts sorter		Fibers shorter than length in column *P*		Weight of fibers, in relation to total weight of all fibers, shorter than length in column *P*
	P	Mean	Mode	Mean	Mode			
	⅛ inch	*⅛ inch*	*⅛ inch*	*⅛ inch*	*⅛ inch*	*Number*	*Percent*	*Percent*
1	6	9. 69	10	8. 67	10	562	15. 51	6. 74
2	6	9. 67	10	8. 74	10	668	17. 67	8. 10
3	6	9. 34	10	9. 20	9	539	9. 01	3. 59
4	8	10. 31	11	9. 92	11	675	15. 26	7. 23
5	7	9. 81	10	9. 11	10	528	14. 97	7. 93
6	4	9. 55	10	8. 89	9	162	4. 60	. 65

The number of fibers of less length than the first positive reading in column *P* were counted. These do not include fuzz up to one-fourth inch long. As can be seen, this number is not small, and when put on a percentage basis, shows even more strikingly the importance of the neglected fibers. On the weight basis, the loss, although not so great, remains considerable. The results shown in the table are the extreme, and can be compared with the result shown in figure 3, where apparently a practically accurate reading of the shorter lint has been achieved. Most readings will not show the extreme differences shown by these readings on long-staple cotton, as recorded in table 7. For example, 10 seeds from a sample of Rowden 5056 averaged 357 fibers less than one-half inch long. These 10 included seeds that showed by photoelectric sorting either no fibers less than one-half inch long or no fibers less than three-eighth inch long. The number of fibers not shown by the sorting would be somewhat reduced if only the fibers shorter than the shortest shown by the photoelectric sorter had been counted. The purpose here is to show at its very worst a source of error in photoelectric cotton sorting as it is now performed. It is to be noted (table 7) that the modes as determined by the two methods practically coincide.

DISCUSSION

The method of calculation at present employed assumes that the profile of the fiber has no marked effect on the light absorption over

its entire length; that the graph of the logarithmic absorption of light caused by the addition of layers of absorptive material approaches a straight line; that the refraction of light probably compensates partially for the logarithmic absorption effect; and that all fibers in a given sample absorb light equally.

The fusiform shape of the fibers has been noted by several workers. Obviously there are more fibers at a point close to the seed coat than at a point farther away from the seed coat. However, in photoelectric sorting, in many cases, especially in samples with long staples, the reading at a point nearest the seed coat is greater (indicating less absorption) than at points immediately after the first reading. (See also table 7.) Hertel and Zervigon (*4*) have noted the same phenomenon. Weights of the ends of fibers are less than the middle portions of equal length of the same fibers (*1*), indicating not only a smaller diameter at the end of the fiber, but also a less absolute amount of absorptive material in the basal end of the fiber. Another reason for the initial low absorption is the shape of the clamp holding the cotton seed. The two prongs of the clamp pass between the fibers and separate them, permitting more light to pass through these openings between the more densely packed fibers. Also the fibers are not quite in the same alignment in relation to the slit next to the seed as they are farther out from the seed coat.

The profile of the fiber cannot readily be changed. It may be that after more experience a correction factor can be derived to correct for the fusiform shape of the fiber. It is likely that a similar correction factor would also have to be applied to the distal ends of the lint. The clamp might be redesigned. One possibility would be to have needle-sharp prongs that would penetrate the seed coat. An objection to this is that such prongs would make it even more difficult than it now is to aline the edge of the seed with the scale.

In theory, the fibers near the seed, being more numerous, should absorb more light than the fewer fibers extending farther from the seed coat. This is expressed ideally by: $\text{Log } \frac{I}{I_o} = -nx$, where I_o equals the original intensity of the light; I equals the intensity of the light after passing n quantity of material with each increment of the material having an absorptive capacity of x. In this equation the ideal is assumed that the absorptive material reflects none of the light, which is not the exact fact as regards cotton fibers.

The effect of reduced light by the absorption of light by added layers of lint is illustrated in the following experiment: Groups of lint, judged to contain about the same number of fibers, were placed on top of one another over the slit of the photoelectric sorting apparatus. After the addition of each group of fibers a reading was recorded. Then the differences between each successive reading were found to determine the absorption by that group of fibers. The differences between successive readings in microamperes were as follows: 12, 24, 15, 42, 21, 17, 19, 7, 19, 14, 4, 8, 3, 8, 5, 7, and 5. The first absorptions are of the same general magnitude, with later a definite trend toward smaller absorptions. There are variations in the above readings because of variations in the number of fibers added from group to group. In general, about 150 fibers were added each time, making

in all about 2,550, or the approximate number of fibers on one-half of a combed seed.

A variation of this experiment in which the light intensity is increased after a number of groups of fibers have been added will increase the absorption of other added groups, but the absorptions will later become lower.

Other possible causes of error are here mentioned. Because the slit through which the light passes is one-sixteenth inch wide, a correction might be subtracted from a reading to account for the various fiber lengths that would fall in the 1/16-inch interval. A possible further correction would be to correct for the size of the length interval of lint drawn past the slit each time. That is, the midpoint of the length class might be the measuring point instead of the bottom point as was used in all work reported in this paper. Thus far, no such corrections have been attempted. But the disagreement between the averages by photoelectric sorting and by measurement of individual fibers (or counting measured fibers) suggests that a correction for photoelectric readings be considered. The effect of changing the arcs bounding the slit from a concentric to an eccentric relationship, as well as other changes in the construction of the apparatus, were noted in describing the photoelectric sorter.

This problem of the accurate measurement of the shorter fibers is of importance in other methods of sorting. The tendency has been to consolidate into one class all fibers of less than a given length, say one-half or three-fourths inch (*6*, *10*). Pope (*7*) has discussed the advisability of omitting the short fibers from a consideration of the mean length and deviations from the mean. He points out that since most short fibers do not enter into the final spining product, the spinner is concerned mostly with the long fibers as they affect the quality of his product. But the cotton breeder is interested in producing as many long fibers in relation to the number of short fibers as possible. In order to determine this relationship properly, it would seem that a quick and accurate measurement of the short fibers is to be desired by the breeder, and that efforts to achieve such measurements should be encouraged. Then, if for certain purposes it is not necessary to have the short fibers sorted in detail, it is still possible to consolidate such readings as may be desired into one length class.

SUMMARY

A description of a basic design for a cotton-fiber sorter employing a photoelectric cell is given. Sorting fibers on seed cotton as to length by this method is comparatively rapid, but sources of error and possible means of improving the technique and the construction of the apparatus are pointed out.

The method of calculating the data is simple, readily providing statistics on average length, modal length, percentage of fibers in any length of group or groups, and data from which measures of dispersion may be obtained.

This apparatus has been applied to many sortings for use in making selections in breeding and genetics studies and in various cotton variety and fertilizer tests.

A close agreement was found between operators and instruments on the same samples, although the instruments have not been calibrated to

a standard. Ten cotton seeds should ordinarily provide an adequate sample for photoelectric sorting. There is a fairly close agreement between photoelectric sorting and measurements of single fibers, as regards average length and modal length.

The principal error in the photoelectric method of sorting fibers appears to be an inadequate consideration of the shortest fibers. The few very longest fibers also are not accurately measured. The effect of the structure of the fiber and the logarithmic absorption of light in relation to these errors are discussed.

LITERATURE CITED

(1) AHMAD, NAZIR, and NANJUNDAYYA, C.
1936. A NEW METHOD AND APPARATUS FOR DETERMINING THE AVERAGE LENGTH AND FINENESS OF COTTON HAIRS. Indian Cent. Cotton Com. Technol. Lab., Technol. Bull. Ser. B, No. 21, 22 pp., illus.

(2) COOK, O. F.
1931. INEQUALITY OF COTTON FIBERS. A DIRECT METHOD OF COMPARING SUBSTAPLE. Jour. Heredity 22: 25–34, illus.

(3) HERTEL, K. L.
1936. APPLICATION OF THE SEED COTTON FIBROGRAPH TO LINT COTTON. Jour. Tenn. Acad. Sci. 11: 147–152, illus.

(4) ——— and ZERVIGON, M. G.
1936. AN OPTICAL METHOD FOR THE LENGTH ANALYSIS OF COTTON FIBERS. Textile Research 6: 331–339, illus.

(5) LOVE, H. H., and BRUNSON, A. M.
1924. STUDENT'S METHOD FOR INTERPRETING PAIRED EXPERIMENTS. Jour. Amer. Soc. Agron. 16: 60–68.

(6) MCNAMARA, HOMER C., and STUTTS, ROBERT T.
1935. A DEVICE FOR SEPARATING DIFFERENT LENGTHS OF FIBERS FROM SEED COTTON. U. S. Dept. Agr. Cir. 360, 16 pp., illus.

(7) POPE, O. A.
1933. THE CALCULATION OF CERTAIN FIBER LENGTH CONSTANTS IN COTTON. Jour. Amer. Soc. Agron. 25: 740–756, illus.

(8) PRESSLEY, E. H.
1933. A NEW TYPE OF COTTON SORTER. Jour. Amer. Soc. Agron. 25: 89–98, illus.

(9) ———
1934. IMPROVING THE UNIFORMITY OF COTTON FIBER BY THE USE OF THE PRESSLEY SORTER. Ariz. Agr. Expt. Sta. Tech. Bull. 54, pp. 127–153, illus.

(10) RICHMOND, T. R., and FULTON, H. J.
1936. VARIABILITY OF FIBER LENGTH IN A RELATIVELY UNIFORM STRAIN OF COTTON. Jour. Agr. Research 53: 749–763, illus.

(11) SOKURAJA-VYSOTSKAJA, O.
1935. MEASUREMENTS OF THE LINT LENGTH OF COTTON UNDER FIELD CONDITIONS. AN APPARATUS CONSTRUCTED BY THE CENTRAL BREEDING STATION, N I H I. Bor'ba za Khlopok 8/9: 127–132, illus. [Original not seen. Abstract in Empire Cotton Growing Rev. 13: 233. 1936.]

(12) STROMAN, G. N.
1934. COTTON BREEDING INVESTIGATIONS, 1928 TO 1932. N. Mex. Agr. Expt. Sta. Bull. 217, 39 pp., illus.

(13) WEBB, R. W.
1932. THE SUTER-WEBB COTTON FIBER DUPLEX SORTER AND THE RESULTING METHOD OF LENGTH-VARIABILITY MEASUREMENTS. Amer. Soc. Testing Materials Proc. 35, v. 32, pt. 2, pp. 1–11, illus.

VARIABILITY IN GERMINATION OF FRESHLY HARVESTED AVENA [1]

By F. A. COFFMAN, *agronomist*, and T. R. STANTON, *senior agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

Freshly harvested seeds often do not germinate satisfactorily. From some points of view this slowness to germinate is undesirable, but the possibility that it may have certain advantages should not be overlooked. Growers have long been cognizant of the heavy losses resulting from the sprouting of grain in the bundle or shock. Obviously, from the practical viewpoint, delayed germination might prove extremely desirable in a wet harvest season. Any variety in which germination is retarded even for a few days, when moisture and temperature conditions are favorable, might escape considerable damage in the field. Comparatively little attention has been given as yet to the few reports of the wide variation in the germinability of freshly harvested seed of different varieties of the small grains. It seemed important, therefore, to determine the extent of such variation among varieties of oats.

REVIEW OF LITERATURE

Sifton (*13, p. 23*) [2] stated that "in the majority of cases there is a slight rise in the germination of oats during the first 4 or 5 years of storage."

Harrington (*7*) cites Kinzel (*10, p. 133*) as saying that oats reached their full germination capacity in 2 months after harvest, but their full germination energy only after 8 or 10 months.

Whitcomb (*15, 16*) stated: "The curing in the field had a slight beneficial effect on the initial germination but it was not well defined" (*15, p. 87*), and "Aging grain in the laboratory for from 4 to 12 weeks decreased the dormancy to a minimum" (*16, p. 32*).

Garber and Quisenberry (*6*) found that in crosses between *Avena sativa* L. and *A. fatua* L. delayed germination is an inherited recessive character and that it is somewhat loosely linked with the *fatua* type of seed articulation. They apparently recognized a variation in degree of dormancy among different strains of *A. fatua* in their cultures.

Eastham (*3, p. 81*) stated:

> In wet, cold harvest years many samples of Black Winter oats do not germinate readily under normal laboratory conditions. Although such Oats will grow perfectly well under field conditions, yet they may only show a germination of from 20 to 30 per cent. after several weeks in test.

Eastham pointed out that merely lowering the temperature of the germination chamber is helpful, or if this proves unsuccessful, the placing of the samples on ice for 4 or 5 days will readily overcome the difficulty.

[1] Received for publication December 22, 1937; issued July 1, 1938.

[2] Italic numbers in parentheses refer to Literature Cited, p. 71.

Foy (*5*), of New Zealand, reported that samples of oats are frequently found that do not give complete germination within the standard testing period of 12 days. He pointed out that almost invariably such samples are newly harvested. Foy's samples undoubtedly represent Red Algerian oats, a type that is grown almost exclusively in New Zealand.

Deming and Robertson (*2*) studied dormancy in three oat varieties. They observed (*2, p. 10*):

> There is considerable dormancy in Kanota oats (*Avena byzantina*) but little, if any, in the types of *Avena sativa* tested. The test agrees with field observations regarding sprouting in the shock. Both Colorado 37 and Nebraska 21 sprout readily in the shock under unfavorable weather conditions.

Johnson (*9, p. 283*) reported that in *Avena fatua*—

> (1) Great variations were found in the after-ripening periods of a number of *A. fatua* selections. (2) Evidence was obtained which strongly indicated that delayed germination is determined by a condition of the seed coat which develops after fertilization. (3) Results from tests of entire panicles indicated a correlation between germinability and the position of the seed in the panicle. (4) The after-ripening period of secondary grains was shown to be much longer than that of primary grains.

Hyde (*8, p. 363*) observed that in comparison with the fully ripened oats those incompletely after-ripened differed in three ways:

> Firstly, the optimum temperature for rapid germination was lower, being in the vicinity of 14° C. Secondly, the speed of germination at low temperatures was higher than that of fully after-ripened oats under the same conditions. Thirdly, at temperatures of 18° or 20° C. and higher, the germination of a proportion of the grain was greatly delayed.

Larson, Harvey, and Larson (*11*) studied the length of the dormant period in cereal seeds collected from the small-grain varietal plots at University Farm, St. Paul, Minn. They found that oats cut in the ripe stage generally had a short rest period. The Gopher variety completed its afterripening and germinated fully within 26 days. They tested early, midseason, and late varieties of common oats (*Avena sativa*) only. A rest period of any considerable length was found only in the late varieties.

MATERIALS AND METHODS

Twenty-five distinct varietal oat types were used in this experiment. These included both wild and cultivated varieties classed morphologically as belonging to six species and subspecies. Both winter and spring varieties of cultivated oats were included. The samples used were typical of the variety in each case, but only one sample of each was grown. It is recognized that there is some possibility that additional samples of these varieties grown under other conditions might have germinated differently than in the experiments reported here.

Most of the varieties tested were strictly spring types, the exceptions being Fulghum (H. C.[3] 726, C. I.[4] 3227), a strain of C. I. 708, Nortex, Fulghum (winter type, C. I. 2500), Aurora, Lee, Hairy Culberson, and Winter Turf. Of these Fulghum (C. I. 3227), Nortex, and Aurora may be grown from either fall or spring seeding, but the other four are grown only from fall seeding. Stanton (*14*) has re-

[3] H. C., an abbreviation of Hays Cereal, indicates the accession number of selections made at the Fort Hays Experiment Station, Hays, Kans.

[4] C. I. refers to accession number of the Division of Cereal Crops and Diseases (formerly Office of Cereal Investigations), U. S. Department of Agriculture.

cently reported on the origin and history of many of these varieties, including Brunker, Fulghum (C. I. 3227), Nortex, Fulghum (winter type, C. I. 2500), Coastblack, Richland, Black Mesdag, Victory, Miami, Cornellian, Markton, Aurora, Victoria, Lee, Hairy Culberson, and Liberty Hull-less. Murphy and Stanton (*12*) and Stanton and Murphy (*14A*) reported on the introduction of Berger and Victoria from South America. The strains of Early Champion, Victor, Winter Turf, White Tartar, and Storm King used were typical of the varietal types classified by Etheridge (*4*). Early Joanette is the only cultivated variety that has not been described in the literature. It is an early black oat of little economic importance, obtained from Illinois by the junior writer in following up an oat varietal survey made in 1919. Its origin is unknown, but on the basis of information available as to its characteristics it may have originated as a selection from Burt or some other variety of *Avena byzantina* C. Koch.

Ludoviciana (C. I. 1781) is a variety of the wild red oat that was obtained from the Mediterranean region about 25 years ago. It is typical of the type known as *Avena sterilis* var. *ludoviciana* (Durieu) Husnot, which does not have hairy awns such as *A. sterilis* var. *macrocarpa* (Moench) Briquet.

The common wild oat used in these investigations was received for varietal identification from a circus company of Allentown, Pa. The sample was taken from a carload of oats that had been screened from hard spring wheat and graded as feed oats. It is a typical gray-seeded variety of *Avena fatua*, and for convenience it has been referred to as the "Allentown" oat (C. I. 3322).

The oats tested were grown in the greenhouse at the Arlington Experiment Farm, Arlington, Va. Plants were harvested as soon as the upper leaves of the primary culms had begun to turn yellow, which occurred during the period from April 3 to May 1, 1933, in the different varieties. The seed was threshed at once, and a sample of straw of each variety was saved for moisture determination. The seed of each variety was divided into 50-kernel samples, placed in open paper containers, and kept in a screen-covered case in the laboratory. Toward the end of the test a few samples of less than 50 kernels were used, because of shortage of seed.

One sample of each variety was placed in the germinator immediately after harvest and the remaining samples at successive intervals of 3 to 4 days thereafter. The seed was germinated between blotters at a temperature of about 60° F. With a few exceptions germination counts were made at 3-day intervals. One sample of each variety was retained for moisture determination. It was weighed each time a new sample was placed in the germinator, and at the end of the test it was oven-dried and weighed.

In these tests any seed showing a protruding coleoptile was considered as having germinated. Ungerminated seed usually remained in the germinator until it rotted, or until the end of the test. The germinator was disinfected with a weak solution of formaldehyde to retard mold.

EXPERIMENTAL DATA

GERMINATION OF SPECIES AND VARIETIES

Germination tests were made on approximately 300 samples of seed of various ages of 25 varieties during the period from April 3 to June 22, 1933. The varieties are divided into the following four groups

according to the promptness of germination of the freshly harvested seed: (1) Prompt, (2) slow, (3) very slow, and (4) delayed, as shown in table 1. Freshly harvested seed or seed not over 4 days old of "prompt" varieties usually had started to germinate by the fifth day after harvest and within 5 to 7 days at least 80 percent had germinated. One variety classed as "prompt" (Liberty Hull-less) started to germinate the second day after harvest but did not germinate 100 percent until the twelfth day. Three-day-old seed of Early Champion germinated 100 percent in 7 days, although the germination of the freshly harvested seed was considerably delayed.

TABLE 1.—*Number of days for initial germination of 25 species and varieties of Avena stored for various periods after harvest*

Type of germination, species, and variety	C. I. No.	Time required for germination after storage for—											
		0 days	2-4 days	4-7 days	8-10 days	11-13 days	14-16 days	17-19 days	19-21 days	22-25 days	26-28 days	36-39 days	47-50 days	74-80 days
Prompt:														
A. sativa:														
Black Mesdag	1877	4	5	3	4	3	3	3	4	2	3	2	4	----
Cornellian	1842	3	3	4	2	3	3	3	3	3	2	3	3	----
Early Champion	1623	6	3	7	4	2	3	3	3	3	3	2	3	----
Hairy Culberson (winter oat)	2505	3	5	3	3	3	3	2	2	3	5	3	3	----
Miami	2245	3	3	3	4	2	3	3	3	3	3	2	3	----
Victory	1145	6	7	4	2	3	3	3	3	3	4	3	3	----
Winter Turf (winter oat)	1570	5	2	6	6	3	3	4	5	4	5	----	----	----
A. nuda:														
Liberty Hull-less	845	2	3	4	3	3	3	4	2	3	3	2	3	----
A. byzantina:														
Fulghum (winter oat)	2500	5	2	3	6	3	5	4	5	4	4	3	3	----
Slow:														
A. sativa:														
Aurora	831	6	6	6	7	4	5	3	6	3	3	4	3	----
Richland	787	6	5	6	4	6	6	3	4	2	3	2	2	----
A. sativa var. *orientalis* (Schreb.) Alefeld:														
Storm King	1602	9	6	6	7	4	5	6	6	3	3	4	----	----
A. fatua:														
"Allentown"	3322	4	5	6	7	6	6	7	4	5	6	5	4	----
Very slow:														
A. sativa:														
Markton	2053	8	27	56	----	6	3	4	2	3	3	2	3	----
Lee (winter oat)	2042	15	12	8	6	6	6	3	3	4	5	5	----	----
Victor	803	12	9	6	7	4	5	3	3	6	3	2	3	----
A. sativa var. *orientalis:*														
White Tartar	1614	27	13	6	7	4	2	3	3	3	3	2	3	----
A. byzantina:														
Brunker	2054	18	6	5	6	4	6	6	7	4	5	4	2	----
Fulghum (H. C. 726)	3227	15	11	12	10	6	6	7	9	8	6	5	4	----
A. sterilis L.:														
A. sterilis var. *ludoviciana*	1781	14	12	7	6	6	7	4	8	6	3	4	5	----
Delayed:														
A. sativa:														
Early Joanette	1092	64	56	14	12	66	62	52	59	49	14	4	9	3
Victoria [1]	2401	68	66	27	6	21	6	8	6	6	6	2	3	----
A. byzantina:														
Berger	2926	29	43	53	8	6	6	3	6	5	4	5	10	----
Coastblack	1025	56	12	8	9	6	6	3	5	7	5	5	7	----
Nortex	2382	(2)	(2)	62	10	56	6	5	6	3	6	7	5	3

[1] A more or less intermediate type that may be classified as belonging to either *Avena sativa* or *A. byzantina*, depending on characters considered.

[2] Did not germinate throughout duration of test, ended June 22.

The percentage germination for those varieties classified as germinating promptly is given in table 2.

TABLE 2.—*Percentage germination of samples of 9 promptly germinating varieties of Avena stored for various periods after harvest*

Variety	Period of storage	Germination after being in germinator for—													
		4 days	7 days	10 days	13 days	16 days	19 days	22 days	25 days	28 days	31 days	41 days	51 days	61 days	71 days
	Days	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Black Mesdag (*A. sativa*, early)	0	56	94												
	4	0	62	72	74	76	88			90				98	
	6	2	88		90	94								100	
	8	24	94	96							98				
	12	2	90	92			94			96		98			
	15	2	100												
	18	8	100												
	21	96	98	100											
	25	84	100												
	28	10	98	100											
	38	40	100												
	48	100													
Early Champion (*A. sativa*, early)	0	0	44	58	60		62					66	96		100
	3	10	100												
	6	0	82	84		86	92			94			96	100	
	9	70	100												
	13	14	98		100										
	15	18	100												
	18	66	100												
	21	56	100												
	24	100													
	27	65	100												
	39	50	100												
	49	90			95										
Cornellian (*A. sativa*, midseason)	0	44	100												
	3	38	94									96		100	
	6	88	98	100											
	10	42	100												
	12	30	100												
	15	90	100												
	18	40	98												
	21	100													
	24	100													
	27	100													
	38	90	100												
	49	76		100											
Miami (*A. sativa*, midseason)	0	40	94	96	98				100						
	3	8	96	98		100									
	6	68	100												
	9	94	100												
	13	40	100												
	15	38	100												
	18	46	98	100											
	21	16	98												
	24	90	100												
	27	100													
	39	70	100												
	49	100													
Victory (*A. sativa*, midseason)	0	0	90				92	94	96		100				
	3	0	16		18	24	30	40	52	54	68	98	100		
	6	56	80		88	90		94	96	100					
	10	26	92	100											
	12	48	100												
	15	76	100												
	18	52	98												
	21	100													
	24	90	100												
	27	100													
	38	100													
	49	68		100											
Hairy Culberson (*A. sativa*, winter)	0	20	54	74	84	90	92		94			96	98		
	3	0	72	82	88								98		
	5	28	82	98											
	8	66	96									98			
	11	76	92	98											
	14	60	94										98		
	17	100													
	19	50	100												
	22	90	95	100											
	26	75	95												
	36	64	72		78	84									
	46	80	98												

TABLE 2.—*Percentage germination of samples of 9 promptly germinating varieties of Avena stored for various periods after harvest*—Continued

Variety	Period of storage	Germination after being in germinator for—													
		4 days	7 days	10 days	13 days	16 days	19 days	22 days	25 days	28 days	31 days	41 days	51 days	61 days	71 days
	Days	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Winter Turf (*A. sativa*, winter)	0	0	4	62	90	100	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	2	38	82	96	98	.....	.....	.....	.....	.....	100	.....	.....	.....
	5	0	62	96	.....	100	.....	.....	.....	.....	.....	.....	.....	.....	.....
	8	0	88	92	94	.....	.....	.....	96	98	.....	.....	.....	.....	.....
	11	2	34	78	82	.....	.....	98	.....	.....	.....	.....	.....	.....	.....
	14	2	90	.....	.....	94	96	.....	.....	.....	.....	.....	.....	.....	.....
	17	60	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	19	0	75	.....	85	95	.....	.....	.....	.....	.....	.....	.....	.....	.....
	22	10	.....	90	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	26	0	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Fulghum, C. I. 2500 (*A. byzantina*, winter)	0	0	2	66	90	100	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	2	26	92	96	.....	.....	.....	.....	.....	.....	.....	100	.....	.....
	5	2	34	96	.....	.....	98	.....	.....	100	.....	.....	.....	.....	.....
	8	0	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	11	4	60	80	86	.....	.....	100	.....	.....	.....	.....	.....	.....	.....
	14	0	90	.....	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	17	25	85	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	19	0	85	90	95	100	.....	.....	.....	.....	.....	.....	.....	.....	.....
	22	10	60	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	26	0	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	36	4	32	.....	58	88	.....	.....	.....	.....	.....	.....	.....	.....	.....
	46	22	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Liberty Hull-less (*A. nuda*, midseason)	0	4	30	48	56	88	94	96	.....	98	100	.....	.....	.....	.....
	2	88	94	96	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	4	88	92	96	98	.....	.....	.....	100	.....	.....	.....	.....	.....	.....
	8	54	76	86	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	11	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	14	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	17	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	21	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	23	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	26	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	38	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	49	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Freshly harvested seed of the *Avena sativa* varieties, Black Mesdag, Cornellian, Miami, Victory, Hairy Culberson, Winter Turf, and Early Champion, germinated promptly, as did also one variety of *A. byzantina*, Fulghum (winter type), and the one variety of *A. nuda* L., Liberty Hull-less.

The germination of varieties classed as "slow" is shown in table 3. These usually had started to germinate by the sixth day after harvest, and seed 2 to 4 days old started germinating promptly. Varieties classed as slow included Richland, Early Champion, and Aurora, belonging to *Avena sativa*, the *A. sativa* var. *orientalis* variety Storm King, and the only *A. fatua* strain tested. No variety classified morphologically as belonging to *A. byzantina* was included in this germination group.

Seed of varieties classed as "very slow" (table 4) started to germinate in from 8 to 27 days; seed 7 days old germinated promptly. These varieties included Markton, Lee, and Victor, classed morphologically as belonging to *Avena sativa;* White Tartar, belonging to *A. sativa* var. *orientalis;* Brunker and Fulghum (C. I. 3227), belonging to *A. byzantina*.

The varieties classed as "delayed" (table 5) did not germinate effectively until about 2 months after harvest, regardless of whether the seed was in the germinator or in dry storage, although partial germination occurred earlier in some samples. The varieties in this group are Early Joanette and Victoria, classified morphologically as belonging to *Avena sativa*, and Berger, Nortex, and Coastblack, belonging to *A. byzantina*, and the strain of *A. sterilis* var. *ludoviciana*.

These results offer an explanation of why poor field stands sometimes are obtained from seed of strains of Red Rustproof oats, such as Appler and Nortex, when sown in the South in August for early fall pasturage.

TABLE 3.—*Percentage germination of samples of 4 slow-germinating varieties of Avena stored for various periods after harvest*

Variety	Period of storage	Germination after being in germinator for—														
		4 days	7 days	10 days	13 days	16 days	19 days	22 days	25 days	28 days	31 days	41 days	51 days	61 days	71 days	81 days
	Days	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Aurora (*A. sativa*, early)	0	0	4	6	----	----	----	----	----	10	16	24	26	28	44	----
	3	0	16	18	20	----	----	24	32	----	34	42	48	----	62	----
	6	0	48	----	----	----	----	----	50	----	52	----	56	58	----	----
	9	0	26	28	30	34	----	36	38	----	----	----	----	46	----	----
	12	6	50	54	56	----	60	62	----	64	----	----	----	68	----	----
	16	0	44	68	----	76	----	----	----	----	----	80	90	----	----	----
	18	10	70	----	----	----	----	----	----	----	----	----	----	----	----	----
	21	0	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	24	4	96	----	----	----	----	----	----	----	----	98	----	----	----	----
	27	96	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	38	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	49	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Richland (*A. sativa*, early)	0	0	2	4	6	8	12	----	----	----	16	38	46	64	72	100
	4	0	2	6	10	20	28	30	32	----	36	48	50	68	100	----
	6	0	50	54	60	64	68	72	----	----	76	----	84	88	98	----
	8	14	46	54	56	----	62	----	----	68	----	74	----	----	94	----
	12	0	38	42	----	46	----	50	----	----	----	54	62	----	78	----
	15	0	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	18	28	92	94	----	96	----	----	----	----	----	----	----	98	----	----
	21	82	88	92	98	100	----	----	----	----	----	----	----	----	----	----
	25	16	80	96	98	100	----	----	----	----	----	----	----	----	----	----
	27	70	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	37	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	47	10	100	----	----	----	----	----	----	----	----	----	----	----	----	----
Storm King (*A. sativa* var. *orientalis*, late)	0	0	----	4	----	20	----	----	----	----	----	----	----	24	56	----
	3	0	40	60	----	----	64	----	----	68	----	----	80	84	88	----
	6	0	80	88	92	----	----	96	----	----	----	----	----	100	----	----
	9	0	84	88	92	96	----	----	----	----	----	----	----	----	----	----
	12	8	72	----	----	80	----	84	88	----	----	96	----	----	----	----
	16	0	68	88	----	----	----	----	----	----	----	----	----	----	----	----
	18	0	80	90	----	----	100	----	----	----	----	----	----	----	----	----
	21	0	70	----	----	80	----	----	----	----	----	----	----	----	----	----
	24	10	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	27	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	38	80	----	----	----	----	----	----	----	----	----	----	----	----	----	----
A. fatua ("Allentown," early)	0	2	36	58	66	72	74	84	----	----	----	----	----	----	----	----
	4	0	50	88	94	----	96	----	98	----	----	----	----	----	----	----
	6	0	54	82	84	90	----	----	----	----	----	----	----	----	----	----
	8	0	48	----	66	----	68	70	74	----	----	----	----	----	----	----
	12	0	80	88	----	----	----	90	----	----	----	----	----	----	----	----
	15	0	74	76	----	----	----	80	----	----	----	----	----	----	----	----
	18	0	70	72	74	76	----	----	----	----	----	----	----	----	----	----
	21	46	66	74	76	84	----	----	----	----	----	----	----	----	----	----
	25	0	48	70	76	----	----	78	----	----	----	----	----	----	----	----
	27	0	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	37	0	80	84	92	----	----	----	96	----	----	----	----	----	----	----
	47	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----

TABLE 4.—*Percentage germination of samples of 6 very slow-germinating varieties of Avena stored for various periods after harvest*

Variety	Period of storage	Germination after being in germinator for—														
		4 days	7 days	10 days	13 days	16 days	19 days	22 days	25 days	28 days	31 days	41 days	51 days	61 days	71 days	81 days
	Days	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Markton (*A. sativa*, midseason)	0	0	----	4	----	----	----	----	----	----	----	----	----	----	42	52
	2	0	----	----	----	----	----	----	----	2	----	----	----	4	46	----
	4	0	----	----	----	----	----	----	----	----	----	----	----	2	10	----
	8	0	4	----	----	----	----	6	----	----	8	----	----	----	20	----
	11	0	60	----	----	----	62	----	----	----	----	----	----	----	----	----
	14	6	56	62	66	----	----	----	----	----	68	82	----	90	----	----
	17	8	22	24	26	28	30	----	32	----	----	38	----	----	64	----
	21	8	68	92	94	----	----	----	----	----	----	96	98	----	----	----
	23	20	80	100	----	----	----	----	----	----	----	----	----	----	----	----
	26	4	94	96	----	----	----	----	----	----	----	----	100	----	----	----
	38	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	49	90	95	----	100	----	----	----	----	----	----	----	----	----	----	----
Victor (*A. sativa*, late)	0	0	----	----	4	8	----	----	10	12	----	----	14	26	80	----
	3	0	----	16	20	28	30	34	36	40	----	----	52	90	----	----
	6	0	64	72	74	76	80	82	----	----	86	----	----	92	----	----
	9	0	66	74	82	88	----	90	----	----	----	92	----	100	----	----
	12	6	54	66	74	----	78	80	----	84	----	86	92	----	----	----
	16	0	66	94	----	96	----	----	----	----	----	98	----	----	----	----
	18	2	92	98	----	----	----	----	----	----	----	100	----	----	----	----
	21	6	90	100	----	----	----	----	----	----	----	----	----	----	----	----
	24	0	98	100	----	----	----	----	----	----	----	----	----	----	----	----
	27	90	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	38	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	49	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Lee (*A. sativa*, winter oat)	0	0	----	----	----	2	6	20	----	24	26	30	32	86	----	----
	3	0	----	----	16	34	40	44	----	46	----	52	----	92	----	----
	7	0	----	32	56	68	70	72	74	76	----	80	100	----	----	----
	9	0	26	50	66	70	82	84	----	----	86	92	----	----	----	----
	12	0	76	92	----	----	----	----	----	----	----	----	98	----	----	----
	15	0	84	88	----	----	----	----	92	94	----	98	----	----	----	----
	18	26	46	56	----	----	----	58	66	68	----	100	----	----	----	----
	21	2	88	----	90	----	94	96	----	98	----	----	----	----	----	----
	24	60	96	----	100	----	----	----	----	----	----	----	----	----	----	----
	26	0	85	----	95	----	100	----	----	----	----	----	----	----	----	----
	38	0	100	----	----	----	----	----	----	----	----	----	----	----	----	----
	49	0	100	----	----	----	----	----	----	----	----	----	----	----	----	----
White Tartar (*A. sativa* var. *orientalis*, late)	0	0	----	----	----	----	----	----	----	4	12	32	38	52	72	----
	3	0	----	----	2	----	6	24	40	52	56	58	72	80	84	----
	6	0	72	80	86	----	88	90	----	92	----	----	----	100	----	----
	9	0	78	88	----	92	----	96	----	----	98	----	----	----	----	----
	12	32	50	56	62	64	70	----	72	----	----	76	----	82	----	----
	16	20	80	90	92	94	----	----	----	----	----	----	----	----	----	----
	18	16	84	96	98	----	----	----	----	----	----	----	----	----	----	----
	21	22	88	90	94	----	----	----	----	----	----	----	----	----	----	----
	24	36	94	----	----	----	----	----	----	----	----	----	----	----	----	----
	27	90	95	----	100	----	----	----	----	----	----	----	----	----	----	----
	38	70	----	100	----	----	----	----	----	----	----	----	----	----	----	----
	49	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Brunker (*A. byzantina*, early)	0	0	----	----	----	----	6	12	48	----	54	72	84	96	100	----
	3	0	8	----	----	12	20	28	34	36	44	74	90	100	----	----
	7	0	4	18	20	22	32	----	----	34	38	62	78	100	----	----
	9	0	26	----	30	34	----	----	----	36	46	66	78	100	----	----
	11	2	36	44	50	----	----	54	56	----	66	80	84	100	----	----
	15	0	22	28	----	----	30	----	34	42	----	46	100	----	----	----
	18	0	76	90	----	----	----	92	96	----	98	----	100	----	----	----
	21	0	60	68	70	78	86	----	----	----	----	----	100	----	----	----
	24	22	90	92	----	----	94	----	----	----	----	96	98	----	----	----
	29	0	66	92	98	100	----	----	----	----	----	----	----	----	----	----
	30	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	51	100	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Fulghum, C. I. 3227 (*A. byzantina*, early)	0	0	----	----	----	2	4	8	----	----	----	----	12	38	----	80
	4	0	----	----	----	4	6	----	----	----	----	16	20	34	76	----
	6	0	----	----	2	----	----	----	----	----	10	12	20	34	40	----
	8	0	----	2	----	----	----	----	----	6	----	10	16	26	62	----
	12	0	2	4	----	----	----	----	----	----	6	10	12	14	64	----
	15	0	26	----	34	----	----	----	----	----	----	36	38	80	----	----
	18	0	6	----	----	8	12	----	----	16	----	18	34	62	----	----
	21	0	----	4	6	----	----	----	----	8	----	16	66	80	----	----
	25	0	----	22	----	24	----	26	----	28	----	46	84	----	----	----
	27	0	40	60	80	----	----	----	----	----	----	----	100	----	----	----
	37	0	48	64	----	----	66	70	72	----	----	80	----	----	----	----
	47	10	20	----	----	30	----	----	----	----	----	----	----	----	----	----

TABLE 5.—*Percentage germination of samples of 6 varieties of Avena showing delayed germination, stored for various periods after harvest*

Variety	Period of storage	Germination after being in germinator for—														
		4 days	7 days	10 days	13 days	16 days	19 days	22 days	25 days	28 days	31 days	41 days	51 days	61 days	71 days	81 days
	Days	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Early Joanette (*A. sativa*, early)	0	0													30	80
	3	0												14		46
	7	0				4				6		8		26	56	
	9	0			2	8		10		12					86	
	11	0													16	
	15	0													26	
	18	0											2	26	32	
	21	0												2		
	24	0											4	20		
	28	0				5	45						80	85		
	38	5				10		15								
	50	0		25	45	75	80									
	74	70	100													
Victoria (*A. sativa*, late)	0	0													40	
	2	0													52	
	6	0								2			6		48	
	9	0	28	32				34						40		
	12	0						2					4	24		
	15	0	2	4		20	24	30	34			38	44	84		
	19	0		10	28	34	54	60	62		66	74	82			
	21	0	20	40		50					60	70				
	24	0	60	65												
	27	0	35		75					80						
	36	75	85			90										
	47	25	75	80				95								
Berger (*A. byzantina*, mid-season)	0	0							4		8			60		
	3	0											5	20		
	6	0												25		
	10	0		15	30	45		50				70	75			
	12	0	20	30	50		60			90						
	15	0	40	50									80			
	18	10	80		90							100				
	21	0	50	85								95				
	24	0	75				80	95			100					
	27	10	90			100										
	38	0	80	90				95								
	49	0	20	100												
Nortex (*A. byzantina*, mid-season)	0	0														0
	4	0														0
	8	0													8	
	11	0		4										8		
	14	0												4		
	17	0	4			6								38		
	21	0	2	12	14	16	18					20	58	60		
	23	0			10							40	50			
	26	15	20										45			
	29	0	35			40						60	70			
	37	0	35			45	55									
	48	0	20	25	30											
	66	20	100													
Coastblack (*A. byzantina*, late)	0	0												24		
	3	0			2		4					20	24	82		
	7	0		4	28	56	58				60	68	90			
	9	0		70	90							100				
	12	0	42	66		68							76			
	15	0	84	86	88	90	92					96	100			
	18	10	42	64	70				78	80		84				
	21	0	66		80		86	90	96		98	100				
	24	0	10	25		90										
	26	0	25	35	40	75	100									
	38	0	100													
	49	0	92													
A. sterilis var. *ludoviciana* (midseason)	0	0				12	20	24				26	28	42	54	64
	2	0			2	6	10			12	16	22	26	28	42	44
	4	0	2				4			10	12	18	22	34	60	
	8	0	2	6		10	16	20	28	30		32	34		60	
	11	0	56	62	64	72		78			80	82	84	98		
	14	0	2	6	10	14		16	18	20		22	30	36		
	17	4		12	20	26	30	34	36	40						
	21	0		32	50	60	74	76			78	82	84			
	23	0	10	40	60		70				80					
	26	10	70				80									
	38	55	80			85										
	49	0	40	55	60	65		70								

The data in general show that the varieties classed morphologically as belonging to *Avena sativa* varied widely, exhibiting all degrees of slowness or rapidity in germination. One variety classed as belonging to *A. byzantina* was prompt in germination, but the other varieties of this species showed more or less dormancy. Varieties of *A. sativa orientalis* were also inclined to be slow to germinate. Among the wild species, *A. sterilis*, the supposed progenitor of *A. byzantina*, was very slow in germinating, and *A. fatua*, the supposed progenitor of *A. sativa*, was classed as "slow."

There is a possibility that some of the varieties classed morphologically as belonging to *Avena sativa* that exhibited more or less dormancy in these tests may have originated from hybrids with *A. byzantina*. Markton, Victoria, and Early Joanette have characteristics other than slow germination that indicate that they may have been derived in part from this species.

Other varieties classed as belonging to *Avena sativa* that give some indications of dormancy are Victor, Richland, Aurora, and Lee. Aurora was originated as a selection from Red Rustproof, and Lee as a hybrid between Aurora and Winter Turf, hence their *A. byzantina* derivation is established. This suggests that dormancy may be helpful as an indicator of the probable origin and relationship of oat varieties.

RELATION OF KERNEL CHARACTERS TO GERMINATION

Several investigators have indicated that certain morphological characters of the oat kernel are associated with dormancy. Table 6 contains a tabular description of the principal distinguishing morphological characters of the oat kernel of the varieties and strains included in these experiments.

Oats having the 5 recognizable kernel colors were tested in the following numbers: Black, 4; gray, 4; red, 6; yellow, 4; and white, 6. Variation in promptness to germinate occurred in all color classes of cultivated oats, but except for Victoria, an oat of reddish-gray color, only black and red oat varieties were classed as having "delayed" germination. Of 10 black or red varieties of cultivated oats, 8 were very slow or delayed and 2 were prompt in germination. *Avena fatua* (gray) and *A. sterilis* (red) were slow in germination. Varieties having the darker-colored kernels appear more frequently to have delayed germination.

Oat varieties may have one or more awns per spikelet in almost all panicles or awns few to almost entirely lacking. The awns may be straight or twisted. Varieties in each germination class included some classed as awnless and some having twisted awns and straight awns. It would seem that awn type is not an index of dormancy in oats.

The type of basal scars in oat kernels may be classed as prominent, obscure, or absent. Of the five strains classed as having prominent basal scars, germination was slow or delayed in all.

Oat kernels with prominent basal scars shatter readily, and varieties of this type probably would not be perpetuated in nature without some degree of dormancy.

The mode of separation between the primary and secondary kernels of the oat spikelet has been described as abscission in *Avena sativa* varieties, fracture in *A. sterilis*, and intermediate in certain varieties

having characteristics of both species (*1A*). Seventeen of the varieties included in these experiments have the *sativa* type of separation or articulation, four varieties were classed as separating by fracture, as in *A. sterilis*, and three as intermediate. The data indicate that dormancy is most often observed in oats having a fracture or intermediate separation. Only one variety so classed germinated promptly. Varieties separating by abscission may or may not have delayed germination.

TABLE 6.—*Kernel characters and type of germination of 25 varieties of Avena*

Species and variety	Kernel characters					Germination
	Type of basal scar	Articulation	Color	Awning	Basal hairs	
Wild species:						
A. fatua, "Allentown."	Prominent	Sativa	Gray	Twisted, geniculate.	Many	Slow.
A. sterilis var. *ludoviciana*	do	Sterilis	Red	do	do	Delayed.
Cultivated species:						
A. byzantina:						
Berger	do	do	do	Straight	do	Do.
Brunker	Obscure	Intermediate	do	Straight and absent.	Few	Very slow.
Coastblack	Prominent	Sterilis	Black	Straight	Many	Delayed.
Fulghum selection (C. I. 3227).	Obscure	Intermediate	Red	Straight and absent.	Few	Very slow.
Fulghum (winter type).	do	do	do	do	do	Prompt.
Nortex	Prominent	Sterilis	do	Straight	Many	Delayed.
A. sativa:						
Aurora	Absent	Sativa	Yellow	Absent	Few	Slow.
Black Mesdag	Obscure	do	Black	Twisted, geniculate.	do	Prompt.
Cornellian	Absent	do	Gray	Absent	do	Do.
Early Champion	Obscure	do	White	Twisted, geniculate.	do	Do.
Early Joanette	do	do	Black	do	Many	Delayed.
Hairy Culberson (winter oat).	Absent	do	Gray	do	Few	Prompt.
Lee (winter oat)	do	do	Yellow	Absent	do	Very slow.
Markton	Obscure	do	do	Twisted, geniculate.	do	Do.
Miami	do	do	White	do	do	Prompt.
Richland	do	do	Yellow	Absent to twisted, subgeniculate.	do	Slow.
Victor	do	do	Black	Twisted, geniculate.	Absent	Very slow.
Victoria	do	do	Gray	do	Few	Delayed.
Victory	Absent	do	White	Straight and twisted, geniculate.	Absent	Prompt.
Winter Turf (winter oat).	do	do	Gray	Twisted, geniculate.	Few	Do.
A. sativa var. *orientalis:*						
Storm King	do	do	White	Absent	Absent	Slow.
White Tartar	do	do	do	do	do	Do.
A. nuda:						
Liberty Hull-less	do		do	Twisted, geniculate.		Prompt.

Of the 25 varieties tested, 4 were classed as having no basal hairs, and *Avena nuda* could not be studied for this character. Four of the five oat varieties classed as having delayed germination had many basal hairs, and the fifth had a few. It has been shown, however, that at least in some oat types, notably fatuoids, having a prominent basal cavity and numerous hairs, delayed germination may not occur.

Dark-colored kernels, prominent basal scars, and numerous basal hairs, that often accompany slow or delayed germination, are frequent-

ly found in the species *Avena fatua*, *A. sterilis*, and *A. byzantina*, in which slow or delayed germination usually occurs. However, apparent relationship of these characters to dormancy may be merely incidental.

RELATION OF KERNEL SIZE TO GERMINATION

Table 7 presents data on size of kernel and percentage of groat in kernels of the oat varieties included in this experiment. The varieties are listed in the order of the weight per 100 kernels.

TABLE 7.—*Kernel weight, percentage of groat, kernel length, and type of germination of 25 varieties of Avena*

Variety	Oven-dry weight of 100 kernels	Groat	Length of kernel	Type of germination
	Grams	*Percent*	*Mm*	
A. fatua, "Allentown"	1.53	63.0		Slow.
A. sterilis var. *ludoviciana*	1.62	58.5		Delayed.
Early Joanette	2.16	82.5	16	Do.
White Tartar	2.19	76.4		Very slow.
Richland	2.26	78.0	17	Slow.
Victoria	2.31	71.1	20	Delayed.
Early Champion	2.40	82.2		Prompt.
Lee	2.44	80.7	16	Very slow.
Black Mesdag	2.59	75.0	19	Prompt.
Cornellian	2.59	80.4	18	Do.
Hairy Culberson	2.62	80.6	15	Do.
Aurora	2.74	83.7		Slow.
Liberty Hull-less	[1] 2.78			Prompt.
Fulghum (C. I. 3227)	2.99	80.2		Very slow.
Victory	3.04	78.2		Prompt.
Winter Turf	3.09	86.3	17	Do.
Fulghum (winter type)	3.12	82.6	17	Do.
Brunker	3.31	75.8	17	Very slow.
Berger	3.48	76.8	18	Delayed.
Victor	3.51	72.2	19	Very slow.
Miami	3.54	78.3		Prompt.
Markton	3.59	77.6	18	Very slow.
Nortex	3.80	80.9	18	Delayed.
Coastblack	4.08	77.7		Do.
Storm King	4.26	70.4		Slow.

[1] Groat only.

On the basis of weight, small- and large-kerneled varieties more frequently exhibited dormancy than varieties with kernels of medium size. The nine varieties that germinated promptly had midsized kernels weighing from 2.40 to 3.54 g per 100 kernels. Liberty Hull-less was included in this group, although, on the basis of groat weight, its kernels might be classed as large.

The highest percentage of groat occurs in the varieties having midsized kernels, and in this group, as just shown, a large percentage of the varieties are prompt in germination. This might indicate that heavy hulls are related to dormancy were it not for certain exceptions among the varieties having delayed germination, such as Nortex, Early Joanette, and Coastblack.

Apparently no relation exists between delayed germination and kernel length, kernel weight, or percentage of groat.

RELATION OF GROWTH HABIT, COLD RESISTANCE, AND MATURITY TO GERMINATION

Among the five varieties of winter oats, germination was prompt in Hairy Culberson, Winter Turf, and Fulghum (winter type, C. I. 2500), very slow in Lee, and delayed in Coastblack.

Additional varieties included in these tests that are extensively grown from fall seeding are Nortex and Fulghum (C. I. 708), of which C. I. 3227 is a selection. Germination was very slow in the strain of Fulghum and delayed in Nortex. Hairy Culberson and a Fulghum (winter type) strain were recently reported by Coffman (*1*) to be more hardy than Winter Turf. These data indicate that delayed germination in freshly harvested oats is not associated with winter growth habit or cold resistance as found in the hardier winter types.

Spring oat varieties ranging in maturity from the earliest to the latest were tested. Among early-maturing cultivated varieties germination was prompt in Black Mesdag and Early Champion and slow in Aurora and Richland, very slow in Brunker and Fulghum (C. I. 3227), and delayed in Early Joanette. Midseason varieties were similarly widely distributed among different germination classes. Cornellian, Miami, and Victory germinated promptly; Markton was very slow; and germination was delayed in Berger and Nortex, the latter a variety grown both from spring and fall seeding. Several late-maturing varieties were tested. Germination was slow in Storm King, very slow in Victor and White Tartar, and delayed in Victoria.

Liberty Hull-less, a midseason oat, germinated promptly. The early-maturing strain of *Avena fatua* tested germinated slowly, and the midseason strain of *A. sterilis* germinated very slowly. The data presented indicate that delayed germination is not necessarily related to time of maturity in oats.

GERMINATION OF PRIMARY AND SECONDARY KERNELS

In recording the data on germination it soon became evident that the primary kernels of the spikelet frequently germinated before the secondary kernels. Thereafter the germination of primary and secondary kernels was recorded separately, and these data are presented in table 8. The weighted average germination of freshly harvested seed of the four prompt-germinating varieties, Cornellian, Miami, Victory, and Early Champion, that eventually germinated 100 percent was 33 percent for the primary kernels, 20 percent for the secondary kernels within 4 days, and 97 and 91 percent, respectively, within 7 days. There was some indication that the secondary kernels germinate relatively more promptly after storage for 6 days or more following harvest than they do within 3 days after harvest.

RELATION OF MOISTURE CONTENT TO GERMINATION

A relationship has been reported between moisture content and dormancy in seeds. Data on the percentage of moisture in the seed and straw of freshly harvested oats and in the seed 3 or 4 days later are presented in table 9.

The data show wide variations in the moisture content of oat varieties in each germination class at the time the seed was harvested. Twelve of the twenty-five varieties had less than 15 percent moisture in the seed at harvest. Varieties having the highest moisture content were not necessarily those slowest to germinate among either the wild or the cultivated species. Seed of freshly harvested Black Mesdag, which germinated promptly, contained 16.3 percent moisture, whereas seed of Coastblack containing 15.3 percent, Berger 13.3 percent, Lee 12.1 percent, and Markton 13.8 percent were delayed or very slow in germination.

TABLE 8.—*Germination of primary and secondary kernels of 12 varieties of Avena*

Variety	Age of seed	Germination							
		3 or 4 days		6 or 7 days		9 to 15 days		24 to 69 days	
		Primary	Secondary	Primary	Secondary	Primary	Secondary	Primary	Secondary
	Days	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cornellian	0	44	44	100	100				
	3	48	15	100	79			100	100
	6	94	75	100	94	100	100		
Black Mesdag	15	2	0	100	100				
Miami	0	63	13	100	87			100	100
	3	13	0	100	90	100	100		
	6	75	59	100	100				
	9	93	95	100	100				
Victory	0	0	0	92	86			100	100
Aurora	6	0	0	57	29				
Early Champion	0	0	0	64	29	82	39	100	100
	3	11	7	100	100				
	9	76	62	100	100				
Richland	8	0	0	82	0	89	9		
	12	0	0	59	13				
	18	48	8					100	100
	21	96	70			100	100		
A. fatua, "Allentown"	8	0	0	63	0	87	0		
	12	0	0	90	40				
	15	0	0	89	36				
Markton	11	0	0	66	52				
Brunker	18	0	0	90	55			100	100
	24	27	13	97	75				
Fulghum	15			45	13				
A. sterilis var. *ludoviciana*	11	0	0	69	20				
	21	0	0	46	17				
Weighted average [1]	All	43	30	65	49			100	100
Do.[1]	0	33	20	97	91			100	100

[1] Average of the 4 prompt-germinating varieties (Cornellian, Miami, Victory, and Early Champion) that eventually germinated 100 percent.

TABLE 9.—*Days to germinate and moisture content of fresh seed and seed 3 or 4 days old, and moisture content of straw at harvest, of 25 varieties of Avena*

Germination type and oat variety	Time in germinator until germination—				Moisture content		
	Began		Reached 80 percent		Seed		Straw
	Fresh seed	Seed 3 or 4 days old	Fresh seed	Seed 3 or 4 days old	Fresh	3 or 4 days old	
	Days	*Days*	*Days*	*Days*	*Percent*	*Percent*	*Percent*
Prompt:							
Black Mesdag	4	5	6	8	16.3	13.3	70.5
Cornellian	3	3	6	7	12.6	12.0	75.1
Early Champion	6	3	49	6	12.8	11.9	75.3
Fulghum (winter type)	5	2	11	8	11.0	11.6	70.0
Hairy Culberson	3	5	11	8	10.0	11.3	68.7
Liberty Hull-less	2	3	14	3	14.5	13.5	73.4
Miami	3	3	6	6	13.8	11.8	73.7
Victory	6	7	6	35	13.8	13.4	61.8
Winter Turf	5	2	11	8	11.2	11.8	66.7
Slow:							
A. fatua, "Allentown"	4	5	21	8	32.6	16.6	70.7
Aurora	6	6	(1)	(1)	16.0	13.1	74.7
Richland	6	5	[1] 74	70	17.7	13.3	79.0
Storm King	9	6	(1)	49	14.6	10.9	76.2
Very slow:							
Brunker	18	6	47	44	15.6	11.5	74.8
Fulghum (C. I. 3227)	15	14	77	(1)	27.1	15.3	72.9
Lee	15	12	59	53	12.1	9.6	70.2
Markton	8	27	(1)	(1)	13.8	13.2	73.2
Victor	12	9	68	62	17.4	12.0	69.1
White Tartar	27	13	(1)	58	19.8	11.6	73.5
Delayed:							
A. sterilis var. *ludoviciana*	14	12	(1)	(1)	16.4	15.3	73.8
Berger	29	40	(1)	(1)	13.3	11.3	75.0
Coastblack	56	12	(1)	53	15.3	9.4	68.3
Early Joanette	64	56	80	(1)	21.6	12.4	79.6
Nortex	(2)	(2)	(2)	(2)	23.3	13.7	68.4
Victoria	68	66	(1)	(1)	19.1	14.8	72.2

[1] Did not germinate as much as 80 percent at end of test. [2] Did not germinate within 81 days.

Within 3 or 4 days after harvest all but three varieties had less than 15 percent moisture and could be considered as approximately air-dry. Periodic fluctuations in moisture content due to changes in atmospheric humidity after that time were too small to affect appreciably the condition of the seed.

During this short interval after harvest, retardation in germination was decreased in some varieties along with the reduction in moisture content. The behavior of the varieties in the delayed-germination groups, however, shows that drying alone can have only a limited effect in breaking dormancy in oats.

The moisture content of the straw at harvest time varied from 61.8 to 79.6 percent in the different varieties. There appeared to be little or no relation between promptness of germination and the moisture content of the straw.

SUMMARY

Freshly harvested seed of varieties of *Avena sativa* showed all degrees of prompt, slow, and delayed germination. The freshly harvested seed of the varieties of *A. byzantina*, *A. fatua*, and *A. sterilis* showed slow or delayed germination. A single variety of *A. nuda* germinated promptly. Indications are that dormancy may prove valuable in tracing the probable origin of oat varieties.

After storage for 7 to 10 weeks after harvest, when the experiment had ended, all varieties except Fulghum, Victoria, and *Avena sterilis* var. *ludoviciana* showed a high 7-day germination. Dormancy was no longer evident in many of the varieties after storage for 4 weeks. No Nortex seed stored less than 66 days germinated satisfactorily, thus explaining the poor field stands frequently obtained following the use of freshly harvested seed of Red Rustproof strains.

Delayed germination was not definitely associated with time of maturity, growth habit, or cold resistance. Freshly harvested seed of some varieties contained considerable moisture and did not germinate so rapidly as seed that was allowed to dry for 3 or 4 days. However, many of the varieties continued to germinate slowly after the seed was air-dry, and delayed germination apparently resulted largely from factors other than moisture content of the seed.

Varieties having dark-colored kernels, prominent basal scars, and numerous basal hairs on the primary kernels were slow in germination. These characters are common to varieties belonging to *Avena fatua*, *A. sterilis*, and *A. byzantina*. However, their relationship to delay in germination may be merely incidental.

The varieties that germinated promptly had kernels of medium size. When freshly harvested the primary kernels germinate more promptly than the small and younger secondary kernels of the spikelet. The difference is less evident after a few days' storage.

LITERATURE CITED

(1) COFFMAN, F. A.
1937. SPECIFIC [SPECIES] HYBRIDIZATION, A PROBABLE METHOD FOR PRODUCING HARDIER WINTER OATS. (Note) Jour. Amer. Soc. Agron. 29: 79–81.

(1A) ——— PARKER, J. H., and QUISENBERRY, K. S.
1925. A STUDY OF VARIABILITY IN THE BURT OAT. Jour. Agr. Research 30: 1–64, illus.

(2) DEMING, G. W., and ROBERTSON, D. W.
1933. DORMANCY IN SMALL-GRAIN SEEDS. Colo. Expt. Sta. Tech. Bull. 5 12 pp.
(3) EASTHAM, A.
1928. SOME TECHNICAL ASPECTS OF SEED TESTING. Jour. Natl. Inst. Agr. Bot. 2: 81–84.
(4) ETHERIDGE, W. C.
1916. A CLASSIFICATION OF THE VARIETIES OF CULTIVATED OATS. N. Y. (Cornell) Agr. Expt. Sta. Mem. 10, pp. 79–172, illus.
(5) FOY, N. R.
1932. DELAYED GERMINATION IN CEREALS. New Zeal. Jour. Agr. 44: 129.
(6) GARBER, R. J., and QUISENBERRY, K. S.
1923. DELAYED GERMINATION AND THE ORIGIN OF FALSE WILD OATS. Jour. Heredity 14: 267–274, illus.
(7) HARRINGTON, GEORGE T.
1923. FORCING THE GERMINATION OF FRESHLY HARVESTED WHEAT AND OTHER CEREALS. Jour. Agr. Research 23: 79–100.
(8) HYDE, E. O. C.
1935. OBSERVATIONS ON THE GERMINATION OF NEWLY HARVESTED ALGERIAN OATS. New Zeal. Jour. Agr. 51: 361–367, illus.
(9) JOHNSON, L. V. P.
1935. GENERAL PRELIMINARY STUDIES ON THE PHYSIOLOGY OF DELAYED GERMINATION IN AVENA FATUA. Canad. Jour. Research (C) 13: 283–300.
(10) KINZEL, W.
1900. ÜBER DIE KEIMUNG HALBREIFER UND REIFER SAMEN DER GATTUNG ASCUTA. Landw. Vers. Sta. 54: [123]–133.
(11) LARSON, A. H., HARVEY, R. B., and LARSON, JOHN.
1936. LENGTH OF THE DORMANT PERIOD IN CEREAL SEEDS. Jour. Agr. Research 52: 811–836.
(12) MURPHY, HICKMAN C., and STANTON, T. R.
1930. OAT VARIETIES HIGHLY RESISTANT TO CROWN RUST. (Note) Jour. Amer. Soc. Agron. 22: 573–574.
(13) SIFTON, H. B.
1921. LONGEVITY OF THE SEEDS OF CEREALS, CLOVERS, AND TIMOTHY. Assoc. Off. Seed Analysts North Amer. Proc. 12–13: 22–24.
(14) STANTON, T. R.
1936. SUPERIOR GERM PLASM IN OATS. U. S. Dept. Agr. Yearbook 1936: 347–414, illus.
(14A) STANTON, T. R., and MURPHY, H. C.
1933. OAT VARIETIES HIGHLY RESISTANT TO CROWN RUST AND THEIR PROBABLE AGRONOMIC VALUE. Jour. Amer. Soc. Agron. 25: [674]–683.
(15) WHITCOMB, W. O.
1923. GERMINATION OF NEWLY THRESHED GRAINS. Assoc. Off. Seed Analysts North Amer. Proc. 14–15: 84–89, illus.
(16) ———
1924. DORMANCY OF NEWLY THRESHED GRAIN. Assoc. Off. Seed Analysts North Amer. Proc. 16: 28–34, illus.

TWO DISTINCT STRAINS OF THE NEMATODE APHELENCHOIDES FRAGARIAE OCCURRING ON STRAWBERRY PLANTS IN THE UNITED STATES[1]

By J. R. CHRISTIE[2]

Nematologist, Division of Nematology, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

In the southeastern part of the United States strawberry (*Fragaria* L.) plants showing symptoms of the disease known as dwarf or crimp, harbor in the bud, between the young unfolding leaves, nematodes of the species *Aphelenchoides fragariae* (Ritzema Bos, 1891) Christie, 1932. That this nematode is the cause of the disease has been demonstrated beyond doubt. In Maryland, symptoms usually appear in early July and begin to diminish in severity during October with the advent of cool weather. Farther south the period of pronounced symptoms may be somewhat extended, but even in Florida, according to Brooks,[3] the disease is most pronounced from July through September.

In certain strawberry plantings on Cape Cod near Falmouth, Mass., there occurs a disease somewhat resembling dwarf or crimp of the South. This condition first came to the attention of officials of the Massachusetts Agricultural Experiment Station in 1932. In the buds of plants showing symptoms are harbored nematodes that appear to be morphologically identical with those from southern-grown strawberry plants. There is little reason to doubt that the nematodes are the cause of the trouble. A microscopic examination of diseased plants in itself is very convincing, since the nematodes are usually present in enormous numbers—a much greater population than is found in the most heavily infested southern plants. The period of maximum symptoms is from about the middle of April to the first of June. At other times during the growing season symptoms are much less severe although not necessarily lacking.

Dwarf in the South, therefore, is a midsummer and early fall disease, while the Cape Cod trouble is primarily a disease of early spring. From the standpoint of control measures the reason for this difference in the seasonal occurrence of symptoms is a matter of considerable importance. The question arises as to whether the Cape Cod trouble and southern dwarf are the same disease behaving in a different manner under different climatic conditions or whether they are two distinct diseases. The close morphological similarity of the nematodes infesting strawberry plants in the two regions makes it impos-

[1] Received for publication November 24, 1937; issued July 1, 1938. This investigation was conducted at the Cranberry Substation, East Wareham, Mass., in cooperation with the Massachusetts Agricultural Experiment Station, and at the Coastal Plain Branch Station, Willard, N. C., in cooperation with the North Carolina Department of Agriculture.

[2] At Willard, N. C., the author was materially assisted by G. A. Meckstroth, associate pathologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

[3] BROOKS, A. N. CRIMP—A NEMATODE DISEASE OF STRAWBERRY. Fla. Agr. Expt. Sta. Bull. 235, 27 pp., illus. 1931.

sible for the taxonomists to differentiate two species. However, races or strains, very similar morphologically but differing physiologically, have long been recognized among certain species of plant-infesting nematodes. That they occur in the genus *Aphelenchoides* has already been suggested.[4] Among the forms previously described as distinct species, *A. olesistus* (Ritzema Bos) infests the leaves of begonias, ferns, and other plants; *A. ritzema-bosi* (Schwartz) infests the leaves of chrysanthemums and other plants; *A. subtenuis* (Cobb) is found in narcissus bulbs; and *A. ribes* (Taylor) is a bud parasite of black currants and gooseberries. All these forms are morphologically so similar to the bud nematode of strawberry plants that Steiner and Buhrer[5] regard them as physiological strains of *A. fragariae*. Hitherto strains have been, for the most part, host strains, i. e., strains more or less specialized to certain plants or groups of plants. The writer is aware of no recorded instance where two distinct strains of a nematode species are confined to a single host plant.

The object of the experiments reported in this paper was primarily to determine the possible effect of climate and other regional conditions on the character and seasonal occurrence of disease symptoms in strawberry plants caused by the nematode *Aphelenchoides fragariae*. Plants infested with this nematode from Cape Cod and plants infested with this nematode from North Carolina were grown side by side at Wareham, Mass., and at Willard, N. C. In every instance where symptoms developed they were characteristic of the region from which the nematodes originated and not of the region in which the plants were grown.

For convenience and brevity the terms "spring dwarf" and "summer dwarf" are proposed for the Cape Cod type of disease and the southern type of disease, respectively. For descriptions and figures of summer dwarf the reader is referred to papers by Plakidas,[6] Brooks,[7] and Christie and Stevens.[8] The last-mentioned paper also describes and figures spring dwarf as it occurs on Cape Cod.

EXPERIMENTAL PROCEDURE

There was constructed at Wareham, Mass., a concrete isolation frame (fig. 1) the walls of which extended 18 inches below and 18 inches above soil level and which was of such size that two transverse walls divided it into three compartments, each 6 by 12 feet. A similar concrete isolation frame was constructed at Willard, N. C. The arrangement and treatment of the plants were the same in both the Wareham and Willard experiments, and the following explanation applies in each case. In compartment *A*, fig. 2, Nos. 1 to 16 were strawberry plants of the Howard 17 (Premier) variety, selected in fields near Falmouth as showing typical symptoms of spring dwarf,

[4] CHRISTIE, J. R., and CROSSMAN, LOUISE. WATER TEMPERATURES LETHAL TO BEGONIA, CHRYSANTHEMUM AND STRAWBERRY "STRAINS" OF THE NEMATODE APHELENCHOIDES FRAGARIAE (ANGUILLULINIDAE). Helminthol. Soc. Wash. Proc. 2: 98–103, illus. 1935.

[5] The first three species mentioned were synonymized in the following publication: STEINER, G., and BUHRER, EDNA M. NONSPECIFICITY OF BROWN-RING SYMPTOMS ON NARCISSUS ATTACKED BY NEMATODES. Phytopathology 22: 927–928, illus. 1932. The last species mentioned (*A. ribes*) was synonymized in: STEINER, G. GOOSEBERRY PLANTS AND LILIES ATTACKED BY THE STRAWBERRY NEMATODE, APHELENCHOIDES FRAGARIAE (ANGUILLULINIDAE). Helminthol. Soc. Wash. Proc. 1: 58–59, illus. 1934.

[6] PLAKIDAS, A. G. STRAWBERRY DWARF. Phytopathology 18: 439–444, illus. 1928.

[7] BROOKS, A. N. See footnote 3.

[8] CHRISTIE, J. R., and STEVENS, NEIL E. STRAWBERRY DWARF. U. S. Dept. Agr. Cir. 297, 8 pp., illus. 1933.

and transplanted into the isolation frame; Nos. 17 to 32 were supposedly disease-free plants of the Blakemore variety from Beltsville, Md., set in the isolation frame and subsequently infested with nematodes from diseased Falmouth plants by dropping the parasites, suspended in water, into the crown of the plant with a dropper.

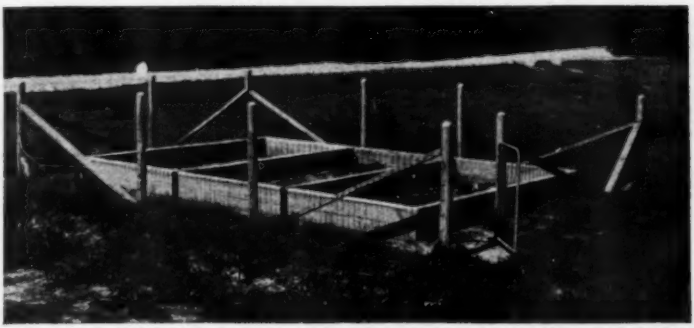

FIGURE 1.—Isolation frame at Wareham, Mass. That at Willard, N. C., was similar in all essential respects.

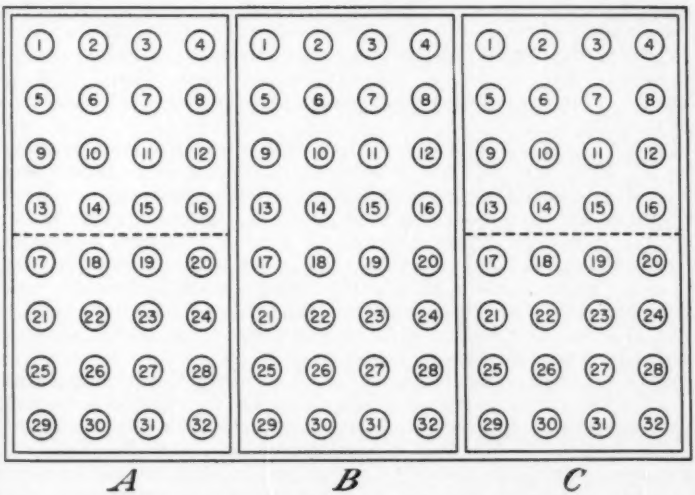

FIGURE 2.—Arrangement of plants in isolation frame at Wareham, Mass., and at Willard, N. C. *A*, 1–16, Plants affected with the Cape Cod disease when selected from fields near Falmouth, Mass., and 17–32, plants experimentally infested with *Aphelenchoides fragariae* from Cape Cod plants; *B*, uninfested controls; *C*, 1–16, plants affected with southern dwarf when selected in fields near Willard, N. C., and 17–32, plants experimentally infested with *Aphelenchoides fragariae* from North Carolina plants.

Compartment *B* was filled with supposedly disease-free plants of the Blakemore variety from Beltsville, to serve as controls.

In compartment *C*, Nos. 1 to 16 were plants of the Blakemore variety selected in fields near Willard, as showing typical symptoms of summer dwarf, and transplanted into the isolation frame. Nos. 17

to 32 were supposedly disease-free plants of the Blakemore variety from Beltsville infested with nematodes from diseased North Carolina plants. In all the compartments a limited number of runner plants were allowed to remain, but enough were removed to prevent the formation of a dense stand. A microscopic examination of runner plants removed in thinning indicated to some extent the degree of infestation at different times of the year. Where runner plants were not formed, a portion of an original plant was sometimes broken away and examined. The Wareham experiment was terminated on August 7, 1936, and the Willard experiment on March 20, 1937. At these times an extensive microscopic examination of plants was made. The situation did not permit keeping these experiments under constant observation. Data were secured during periodic visits to the two localities.

THE WAREHAM EXPERIMENT

Plants 1 to 16, compartment *A*, were set into the isolation frame June 28, 1934. Distinct sypmtoms of spring dwarf appeared on six of the plants during May 1935 but were not as pronounced as when the plants were selected for transplanting the preceding year. None of the plants showed distinct symptoms during the spring of 1936. When the experiment was terminated August 7, 1936, a miscrosopic examination showed an occasional specimen of *Aphelenchoides fragariae* in some of the plants. In this locality, however, plants affected with spring dwarf rarely harbor a large population during late summer. Throughout the course of the experiment these plants remained stunted. Plant 11 set one small runner plant; otherwise runners were not formed.

Plants 17 to 32, compartment *A*, were set into the isolation frame June 25, 1934, and infested 2 days later. So far as could be determined this attempt to establish an infestation was not successful, perhaps owing to subsequent wilting of the plants during midday from the effects of transplanting. A second attempt to establish an infestation was made May 24, 1935, and was successful, at least for some plants, although clearly recognizable symptoms never developed. An occasional specimen of *Aphelenchoides fragariae* was found in some of the plants on microscopic examination when the experiment was terminated August 7, 1936.

Plants 1 to 16, compartment *C*, were set into the isolation frame July 12, 1934. Symptoms of summer dwarf were retained throughout the summer but decreased somewhat in severity following transplanting and largely disappeared during September. On September 20, one runner plant from each of eight original plants was removed and examined. Of these, two had a moderately heavy infestation, three harbored a few specimens, and three were not infested. No indication of symptoms appeared during the spring and summer of 1935 or 1936. All the original plants that were still alive and most of the runner plants were carefully examined August 7, 1936, and not a specimen of *Aphelenchoides fragariae* was found.

Plants 17 to 32, compartment *C*, were set into the isolation frame June 25, 1934, and infested July 13. On September 20, of the original plants, six showed summer dwarf symptoms of varying degrees of severity and two were dead. The most pronounced symptoms were on the runner plants, many of them resembling in every respect

similarly affected plants in the South. One runner plant from each of 12 of the original plants was examined; 7 had a moderately heavy infestation, 2 harbored a few specimens, and 3 were not infested. Of these plants some of the most heavily infested showed moderate symptoms, the others were not noticeably abnormal. No indication of symptoms appeared during the seasons of 1935 and 1936. On August 7, 1936, a careful examination of all the remaining original plants and many of the runner plants failed to disclose the presence of *Aphelenchoides fragariae*.

None of the uninfested plants in compartment *B* developed recognizable symptoms. From time to time throughout the duration of the experiment, runner plants were removed and examined. All plants whose appearance could in any way be regarded with suspicion were included among those examined, but *Aphelenchoides fragariae* was never found.

THE WILLARD EXPERIMENT

Plants 1 to 16, compartment *A*, were set into the isolation frame May 29, 1935. They were shaded with burlap for a few weeks, then covered with slat frames providing one-third shade until September 14, when all shade was permanently removed. Since diseased Blakemore plants were not available in the Falmouth region, it was necessary to use Howard 17 plants, a variety that does not thrive in the southern climate. Furthermore, these plants could not be selected until considerably past the time when transplanting can be done most successfully at Willard. Partial shade during the hottest part of the first summer seemed advisable. Many of these plants never entirely lost their abnormal appearance during the summer of 1935, although such symptoms as persisted were much less pronounced than when the plants were selected for transplanting. On January 16, 1936, three of these plants showed quite pronounced symptoms resembling infested plants on Cape Cod during May, and several others showed slight but recognizable spring dwarf symptoms. A part of the crown of two of the plants showing slight symptoms was removed for examination; each harbored a heavy population of *Aphelenchoides fragariae*, characteristic of spring dwarf. During the summer of 1936, as during the preceding summer, some of these plants never entirely lost their abnormal appearance although such symptoms as persisted were much less pronounced than during early spring. In 1937, observations were made on March 20, when the experiment was terminated and the plants were examined. All plants were small and had a stunted appearance. One showed pronounced symptoms and was heavily infested. Eight showed slight but recognizable symptoms; of these, three harbored a heavy infestation, five a moderately heavy infestation, and one a few specimens. Of the remaining plants, four did not show symptoms and were not infested and three were dead.

Plants 17 to 32, compartment *A*, were set into the isolation frame December 7, 1934, and infested May 29, 1935. These plants were shaded in the same manner and for the same period as Nos. 1 to 16. All plants were apparently normal on July 18, 1935, but by August 13, three had developed suspiciously crinkled leaves and one showed distinct symptoms. By September 14 these abnormalities had dis-

appeared. On January 16, 1936, four plants showed moderately pronounced spring dwarf symptoms and several others showed slight but recognizable symptoms. In some cases traces of these abnormalities persisted throughout the summer. On March 20, 1937, seven plants showed recognizable symptoms and all were heavily infested; three plants did not show symptoms and were not infested; and six plants were dead.

Plants 1 to 16, compartment *C*, were set into the isolation frame July 6, 1934. Distinct symptoms reappeared on nine of the plants during July 1935 but were less pronounced than when the plants were selected for transplanting the previous year. Recognizable symptoms appeared on some of the plants during August and September 1936 but were less pronounced than in 1935. Very few runners were produced at any time, although the original plants became large with many subdivisions of the crown. On March 20, 1937, a microscopic examination revealed only an occasional specimen of *Aphelenchoides fragariae* on some of the plants. This was in agreement with the nematode population usually found in infested southern plants at this time of the year but was in marked contrast to the very heavy infestation encountered in plants 1 to 16, compartment *A*, infested with the Cape Cod strain.

Plants 17 to 32, compartment *C*, were set into the isolation frame December 7, 1934, and infested July 19, 1935. Ten of the plants had developed typical symptoms by September 14, 1935. Symptoms were also conspicuous on many of the runner plants, of which a greater number had been set than was the case with plants 1 to 16. During midsummer of 1936 recognizable symptoms appeared on some of the plants, but they were less pronounced than during the preceding summer. When the plants were examined microscopically on March 20, 1937, a specimen or two of *Aphelenchoides fragariae* were found on some of them by careful searching.

The plants in compartment *B* were set into the isolation frame December 7, 1934. No indication of symptoms was seen during 1935. From time to time runner plants and any plants that seemed abnormal in appearance were removed for examination, but all were free from the parasite. Late in the summer of 1936 two plants developed symptoms of summer dwarf, and microscopic examination showed that both were infested with *Aphelenchoides fragariae*. The origin of this infestation is not known.

DISCUSSION

Diseased strawberry plants from Cape Cod, when grown at Wareham, Mass. (plants 1–16, compartment *A*) and diseased strawberry plants from North Carolina, when grown at Willard, N. C. (plants 1–16, compartment *C*), showed most severe symptoms during the first year and progressively less severe symptoms thereafter. In general, both lots produced few runners. The plants at Wareham experimentally infested with the Cape Cod strain (plants 17–32, compartment *A*) were little affected by the parasite, and their growth throughout the experiment was about the same as that of the controls. For some reason the experimental infestation did not result in a sufficient nematode population to materially affect the plants. The plants at Willard experimentally infested with the southern strain (plants

17–32, compartment *C*) produced runners rather freely the first year but thereafter produced fewer runners than did the controls.

Diseased southern plants grown at Wareham (plants 1–16, compartment *C*) produced few runners during the experiment even though the nematode population gradually disappeared. Plants at Wareham experimentally infested with the southern strain (plants 17–32, compartment *C*) produced runners rather freely throughout the experiment. During the first year many of these runner plants showed typical and quite pronounced symptoms of dwarf; but these symptoms did not reappear during the following two summers, apparently because of the gradual reduction of the nematode population that was unable to maintain itself under northern conditions.

The behavior of diseased Cape Cod plants grown at Willard (plants 1–16, compartment *A*) and of plants experimentally infested with the Cape Cod strain (plants 17–32, compartment *A*) was about the same. Symptoms were clearly recognizable in 1936 as early as January 3, when the plants harbored the heavy nematode population characteristic of infested plants during April and May in the vicinity of Falmouth. It should be recalled in this connection that from January to March plants affected with summer dwarf and growing under southern field conditions never develop pronounced symptoms or harbor a large nematode population.

During January, February, and March, 1931, the number of *Aphelenchoides fragariae* harbored by each of 65 plants was determined. These plants were of the variety Klondike, selected in fields near Chadbourn, N. C., during the summer of 1930 when all showed pronounced symptoms. Counts were made on five plants each week. The greatest number of *Aphelenchoides fragariae* specimens found in any plant was 80, and the average for the 3 months was 10 per plant. Counts on 5 plants per week, or a total of 20 plants, from the same locality during September 1931 gave an average of 221 specimens per plant, the greatest number in any one plant being 605. Five plants selected in a field near Falmouth on April 24, 1934, and showing typical symptoms of spring dwarf harbored approximately 2,800, 8,620, 7,800, 9,700, and 12,900 specimens of *Aphelenchoides fragariae*, respectively.[9]

The intensity of the nematode infestation and the time of the year when it becomes greatest are the most outstanding differences between spring dwarf and summer dwarf. The plants in compartment *A* at Willard affected with spring dwarf retained the tendency to harbor a large population of *Aphelenchoides fragariae* during early spring, when plants affected with summer dwarf have only a few specimens. During January 1936 and March 1937, many of the infested plants in compartment *A* had a much greater nematode population than is found in infested North Carolina plants during the period of maximum symptoms.

These experiments indicate that the differences between the behavior of the parasite causing summer dwarf and that causing spring dwarf and the respective seasonal occurrence of symptoms are not due to the influence of climate or other regional conditions. All the facts indicate that two diseases are being dealt with which result from two distinct races or strains of *Aphelenchoides fragariae*. The

[9] CHRISTIE, J. R., and BOYD, O. C. APHELENCHOIDES FRAGARIAE ON CAPE COD STRAWBERRIES. U. S. Bur. Plant Indus. Plant Disease Reptr. 18: 45–46. 1934. [Mimeographed.]

potential geographic range of each disease, however, may be restricted by climatic conditions. That summer dwarf can become permanently established as far north as Massachusetts seems doubtful. Spring dwarf occurs in the regions of Falmouth and Dighton, Mass., but has not been found elsewhere in the New England States. What is in all probability the same disease has been found near Merchantville, N. J., on the Eastern Shore of Maryland, and in Fairfax County, Va. From the results of the Willard experiment one would conclude that this disease probably can and perhaps does occur as far south as North Carolina.

SUMMARY

When strawberry plants showing typical symptoms of summer dwarf were moved from North Carolina to Wareham, Mass., they retained, to some extent, both their symptoms and their nematode population throughout the remainder of the growing season. When strawberry plants growing at Wareham were experimentally infested during early summer with *Aphelenchoides fragariae* from southern plants, typical symptoms of summer dwarf were freely developed during July and August. In neither case were recognizable symptoms developed during the following two summers, and at the end of the third season the plants had entirely lost their infestation. There was no tendency for northern climatic conditions to change the seasonal occurrence of symptoms; but instead, symptoms disappeared after the first summer, apparently owing to the gradual extermination of the nematodes.

When strawberry plants showing typical symptoms of spring dwarf were moved from Falmouth, Mass., to Willard, N. C., neither the character nor the seasonal occurrence of the disease was changed except that symptoms occurred much earlier in the year. Plants growing at Willard and experimentally infested with nematodes from Cape Cod plants behaved in a similar manner. After two summers in the southern climate there was no significant reduction in the nematode population.

It is concluded that spring dwarf and summer dwarf are caused by two different strains of *Aphelenchoides fragariae* that are indistinguishable morphologically but differ physiologically.

U. S. GOVERNMENT PRINTING OFFICE: 1938